Acoustic properties of polymer foam composites blended with different percentage loadings of natural fiber

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Abstract. This study investigates the acoustic properties of polymer foam composites (FC) filled with natural fiber. The FC were produced based on crosslinking of polyol, with flexible isocyanates and wood filler. The percentages of wood filler loading are 10, 15, and 20 wt% ratio of polyol. The FC also has a thickness of 10, 20 and 30 mm. The acoustic properties of the FC were determined by using Impedance Tube test, Optical Microscope (OM) and Mettler Toledo Density Kit test. The results revealed that FC20 with 30 mm in thickness gives the highest sound absorption coefficient (α) with 0.970 and 0.999, at low and high frequency respectively. FC20 also shows smallest pores structures size with 134.86 µm and biggest density with 868.5 kg/m³ which helps in absorbing sound. In this study, FC with different percentage loading of wood filler and different foam thickness shows the ability to contribute the absorption coefficient of polymeric foam at different frequency levels. Lastly, this type of FC is suitable for any type of sound absorption applications material.

1. Introduction

As the undesirable noise has become hazardous, the demand for residential safety and better environment becomes a major requirement to societies. Several studies focusing on sound absorbing materials have been performed to find the solution for this problems. This material plays important roles in the engineering of acoustic such as the control of industrial noise control, room acoustics, automotive acoustics and studio acoustics [1, 2]. Sawmill and furniture manufacturing industry have increased their production rate due to high demand. The wood waste product from this industry can increase environmental issues, where the wood need to be disposed of through burning or throw away into the river that causes pollution [3, 4]. The wood waste product should be reuse or recycle to create a valuable product for future as well as reducing the environment pollution [5–7]. This practice also uses the concept sustainability of technology manufacturing that we have known the sustainability is our measurement the credibility of most all the manufacturing industry by today to illustrate the green environment for future generation [8].

Polymer is known as engineering material because it is useful for many application. Polymeric foam also one of possible material to use and fabricated with waste wood dust [9–11]. Thus, it could generate into useful application of sound absorbing material. Sound characteristic with different ratio of polymer composite could contribute to high sound absorption at lower absorption coefficient level. The combination of this two material will form a new composite which has better sound properties. The composite is known as polymer foam composite (FC). The FC were developed based on...
crosslinking of polyol, flexible isocyanates and wood filler. In this study, Red Meranti wood was used because of its excessive sources of the furniture manufacturing. The acoustic characteristic properties (sound absorption coefficient) of the composite were determined to analysis the property filler in polymer foam composites. Red Meranti wood is chosen because of their availability. Wood dust is lignocellulosic by product of sawmill industry that is available at low cost [3, 7, 12]. Sawdust has been produced excessively in sawmill and furniture industry so we can try to recycle to valuable product to increase their sustainability in this industry.

2. Methodology

2.1. Polymer foam composites (FC) preparation
The foam was prepared by once shot method. All ingredient were mixed together to produce the FC. The FC is prepared by mixing the polyol and isocyanate at a ratio of 1.0:0.5 respectively. The polyol was poured into the plastic container approximately 3.0g and the wood filler was mixed with a polyol (10%, 15% or 20% of polyol weight ratio). Then, the isocyanate was poured together into the mixture. The mixture is allowed to cure and expand at room temperature for 24 hours. After the FC were completely cured, the samples were cut by using a knife and cylindrical shape of Teflon mold with a diameter of 100 mm and 28 mm [3, 10, 11]. Table 1 shows the proportion ratio of polyol, isocyanates and wood filler for the FC.

| Sample  | Polyol (g) | Isocyanates (g) | Woods filler (g) |
|---------|-----------|-----------------|-----------------|
| PU Foam | 30        | 15              | 0               |
| FC10    | 30        | 15              | 2.25            |
| FC15    | 30        | 15              | 6.75            |
| FC20    | 30        | 15              | 9               |

2.2. Impedance tube test
The sound absorption coefficient for the samples were measured using the Impedance Tube test that consists of a adjustable filter, propagation tube, large sample tube 100 mm diameter for low frequency 0 to 1500 Hz, small sample tube 28 mm diameter for high frequency 1500 to 6000 Hz and two-microphone method and a digital frequency analysis system for the measurement of normal incidence sound absorption coefficient and normal specific acoustic impedance ratios of materials. Sound absorption of polymer foam composites was measured at 0-6000 Hz according to ASTM E1050.

2.3. Optical microscope (OM) test
OM was used to identify the effect of filler loading on the size of pore polymer foam composites (FC). This test was very important due to the filler loading affected the acoustic properties. The FC samples were prepared in small size in order to fit into the sample holder. The magnification of OM lens was adjusted into 10x magnification. The type of OM used is Nikon Eclipse LV150NL.

2.4. Mettler toledo density kit (HR250AZ) test
This density test was conducted to identify the difference in density of foam before and after added with the wood filler. Four samples for every polymer foam composites (FC) with size 10 x 10 x 10 mm were prepared to get the accurate value of density by using the average result. This research was used Buoyancy Method according to European Standard EN 993-1 to identify the density of FC. Equation (1) below is used to calculate the density.

\[
\text{Density, } \rho = \frac{\text{Weight of sample in air (g)}}{[\text{Weight of sample in air (g)} - \text{Weight of sample in liquid (g)}]} \times \text{Density of liquid (g/cm}^3\text{)} \quad (1)
\]

where, density of liquid (methanol) = 0.798 g/cm³
3. Results and discussions

3.1. The effect of percentage loadings and thickness

Figure 1 graph shows the sound absorption coefficient level (α) results with three different thickness (10 mm, 20 mm and 30 mm) of polymer foam composites (FC) by using the Impedance Tube test. Figure 1(a) shows the result for PU foam, where, at low and high frequency region the highest α is contributed from 30 mm thickness foam with 0.772 and 0.960 respectively. Furthermore, Figure 1(b) shows the results for FC with 10% wood filler loading. At low and high absorption frequency level, the highest α is contributed from the highest thickness of 30 mm foam with 0.951 and 0.993 respectively. Figure 1(c) shows the result of FC for 15% percentage loading, where, at low and high frequency absorption level the highest α is 0.969 and 0.998 respectively with thickness 30 mm. Meanwhile, Figure 1(d) also shows the result of FC for 20% percentage loading which is at low and high frequency absorption level the highest α is contributed from 30 mm thickness foam with 0.970 and 0.999 respectively. In comparison, FC20 gives the highest α as compared to the overall results for PU foam and others FC.

The highest α is due to the highest FC thickness and wood filler percentage loading, the higher the sound resonant frequency will accumulate and it will dissipate energy of sound more efficiently through the foam [13]. The friction will increase when thickness increase due to the longer the path of the sound wave, and increase the sound absorption coefficient [11,14–16]. The highest absorption occurs at a resonant frequency of quarter wavelength of the wave sound [15]. A porous material is effective from the sound absorption point of view when the thickness is approximately one-tenth the wavelength of the incident sound [15–17]. Increase in sound absorption especially at low frequencies when the material thickness increases; at high frequencies, material thickness has a lower effect on sound absorption [15].

![Graph showing sound absorption coefficient vs. frequency](image_a.png)

![Graph showing sound absorption coefficient vs. frequency](image_b.png)
3.2. The effect of pore size

Figure 2 shows the microstructure images of polymer foam composites (FC) and Figure 3 shows the average pore size (µm) results for overall FC and PU foam. The smallest average pore size for FC is FC20 followed by FC15, FC10 and PU foam with 134.86 µm, 168.82 µm, 175.22 µm and 185.21 µm respectively. Based on the average size of pore for overall samples, it is best to conclude that with the increasing of filler percentage loading, it will decrease the pores size of polymer form composite. The pores size allows the sound wave passing through the sound absorbing material and dissipated sound energy and damped itself [3, 4, 18]. Smaller pore size gives more collision occurs between the sound wave and cell wall, longer the path of reflection and refraction and more the absorption energy, thus, create greater sound absorption coefficient [3, 11].

Figure 2. Microstructure image of (a) PU foam; (b) FC10; (c) FC15; and (d) FC20.
3.3. The effect of density

Figure 4 shows the average value of density for four samples of polymer foam composites (FC) with different percentage loading of wood filler loading. It shows that the PU foam gives smallest density value of 827.4 kg/m$^3$. FC with 10%, 15% and 20% shows increment in density value of 844.0 kg/m$^3$, 850.8 kg/m$^3$ and 868.5 kg/m$^3$ respectively. FC with wood filler has a greater impact on the density values of the increase of percentage filler loading compared to PU foam. This result shows that the increase of density enhanced the ability to absorb more acoustic energies. This is because the number of fiber increases per unit area when the density is increasing and makes more sound energy losses as the surface friction increase, thus makes the sound absorption coefficient, $\alpha$ increases [15, 17, 19].

Figure 4. Average density (kg/m$^3$) for overall polymer foam composites

4. Conclusion

The results obtained concluded that the studies are successfully done. The analyzed data shows that acoustics properties of polymer foam composite are affected by different percentage loading of wood filler, thickness, pore size and density. FC20 with 30 mm in thickness gives the highest of the sound absorption coefficient, $\alpha$ with 0.970 and 0.999 at low and high frequency level respectively. FC20 also gives the smallest pore size with 134.86 µm and bigger density with 868.5 kg/m$^3$. In conclusion, the
best sample material from this study it is from a wood virgin, that mostly gets the higher value of percentage wood filler loading and the higher thickness of foams to create the perfect material of sound absorption coefficient.

5. References
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