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Research article

Structural and acoustical performances of oil palm trunk waste – Elastomeric thermoplastic polyurethane composite

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A R T I C L E I N F O

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Sound transmission
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A B S T R A C T

In this report, naturally available materials have been utilized in the development of acoustic absorbers. This work presents the study of the effect of oil palm trunks dust (OPTD) loading to the mechanical and acoustical properties of elastomeric thermoplastic polyurethane (TPU). Four composite sheets of 3-mm thickness were prepared by varying the OPTD loadings with 10–40% wt into the polyurethane. Density, modulus elasticity, sound absorption coefficient and sound transmission loss of the samples were measured according to corresponding standards. The OPTD is found to reduce the density of the elastomeric polyurethane and at the same time, it increases the Young's modulus up to 215 MPa. The composite material can be applied as sound absorber panel installed in front of a rigid wall with an air gap. Increasing the air gap, thus lowering the air stiffness, shifts the absorption peak to a lower frequency. With OPTD loadings, the formation of micro-pores in the inner structure helps to improve the peak of sound absorption of the panel at the resonant frequency which can reach above 0.9. As the OPTD loading has effect on density, the effect on the sound transmission loss at the mass-controlled region is also apparent.

1. Introduction

In line with occupational safety and hazard criteria demanded by the world health organization (WHO), machinery noises are known as one of the major problems currently encountered by most industries. In most industrial sites, noise generated from constant machinery operation can reach a level that is not safe for human ear, especially for workers who work near to machines in such enclosed spaces. According to WHO, exposure of noise level more than 85 dBA for 8 h is not healthy for workers. Therefore, a reduction of occupational noise level has become mandatory in several countries which can be accomplished by utilization of acoustic materials.

Naturally available fibrous materials have been utilized in the development of structural and acoustic materials. Consideration on

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their utilization is mainly due to their abundant resource availability, lower process cost, environmentally friendly and biodegradable factors [1–6]. The utilization of these fibers as acoustic materials can be in the form of compacted fibers specimens and in the form of composite material. A study by Zhu et al. concluded that natural fibers with small average diameter and able to well compacted are the most promising for absorbing sound due to increasing chance of friction between sound waves and fiber [7]. Similar findings also stated by Gomez et al. [8], on their study on the acoustical properties of coir, fique and denim fibers bind with latex. By performing statistical analysis, they found that fiber diameter and density have a significant effect on sound absorption while latex content does not affect the sound absorption. By compacting sugarcane fiber into different density and fiber diameter samples, Othmani et al. [9] conclude that sugarcane fiber is a good sound absorber material at medium and high frequencies. They also suggest that the Jonhson-Allard sound propagation model provided good fitting with experiment data in predicting absorption coefficient for vegetal fiber. A study by Taban et al. on compacted date palm empty fruit bunches (DPEFBs) indicate that the DPEFBs has comparable sound absorption properties to coir and sugarcane particularly at frequencies below 2.5 kHz, however the absorption properties are still lower than the palm oil, hemp and kenaf fibers [10]. Study by Hariprasad et al. on the acoustical properties of polypropylene (PP) reinforced with various plant fibers indicated that thickness of the composite sample has a significant effect on lower frequencies and milkweed fiber, or sisal fiber can be used as a PP reinforcement for better sound absorption for 10-mm thick sample [11].

Malaysia is known as one of the largest producers and exporters of palm oil in the world. Consequently, tons of lignin and cellulose biomass waste from palm oil industries are produced annually. There were more than 90 kilotons of biomass waste from palm oil industries produced in 2007 [12,13]. This condition led to growing concern on the utilization of palm oil waste for various functions to reduce its effect to environment. The use of palm oil fibers has become favorable waste that can be utilized as biomass energy and advances material resources [14–19]. However, less attention still given to the utilization of palm oil waste in form of powder or particles as reinforcing component for composite material although the application of wood powder or saw dust as filler in the development of polymer matrix composite has been acknowledged. Study by Crespo et al. suggest that the content of sawdust particles can influenced the mechanical properties of Vinyl plastisol (PVC + Plasticizer) [20]. Study by Md Som et al. [21] suggests that that combination of palm oil fiber and wood dust can be utilized in particleboard manufacturing. In the previous study, we found that addition of oil palm frond dust shows better hardness and tensile strength to thermoplastic polyurethane compared to the oil palm frond fiber [22]. Wardani et al. shows that palm oil trunk powder able to improve the physical and mechanical properties of recycled polypropylene pretreatment is required to the palm oil trunk prior to sample fabrication [23]. Moreover, the fly ash from palm oil waste also can be utilized as filler for various metal composite material. Study by Tugiman et al. [24] indicate that addition of palm oil fly ash particles are able to enhance the hardness and wear resistance of aluminum matrix composites.

Control of noise and vibration are commonly accomplished by using insulation, dampening, and padding materials. Several works related to the potential of palm oil fiber as acoustic materials have been published. A study Samsudin et al. on effect of different form of empty fruit bunch (EFB) coir and dust concluded that dust of empty fruit bunch samples absorbed more sound energy compared to coir samples at both low and high frequency region [25]. Density and thickness of acoustic materials are two factors that determine the sound absorption properties [26]. Study by Or et al. [27] on acoustical properties of oil palm empty fruit bunch fibers indicated that absorption performance can be improved by increasing the thickness of the sample and also by having optimum densities of fibers. A work by Kalaivani et al. [28] on acoustic properties oil palm trunk fiber concluded that compacted oil palm trunk fiber sample with density of 100 kg/m^3 and thickness of 12 mm exhibit a maximum absorption coefficient of 0.99. Moreover, Manik et al. found that physical, mechanical, and acoustical properties of the raw oil palm trunk can be improved [29] by performing alkali treatment and impregnating oil palm trunk wood with melamine-formaldehyde (MF) resin. They indicate that the chemical treatments have an impact on the fraction and inner pore dimensions of the OPT wood, consequently, affecting the number of inner pores which influence the sound absorption properties.

Polyurethanes are versatile substances that allow creation of both thermoplastics and thermosetting polymer with physical properties ranging from exceptionally soft to hard and rigid form. To address the potential of bio waste in the palm oil industry, we consider using the oil palm trunks (OPT) waste as filler in development of thermoplastic polyurethane (TPU) bio-composite. Several studies on acoustical properties of polyurethanes have been conducted by researchers. Study by Gwon et al. point out a low sound absorption efficiency on low density flexible polyurethane foams [30]. A work by Park et al. [31] conclude that polyurethane foam with the best cell openness showed better sound absorption performance than the foam with double mass density. Furthermore, it is found that the acoustical properties of polyurethane can be improved by addition of other materials such as fibers and particles. Study by Gayathri et al. [32] shows that sound absorption coefficient of polyurethane can be increased with addition of nano particles fillers such as nano silica and nano clay. A work from Chen and Jiang reported that polyurethane foam composites with 8% of bamboo chips shows good sound insulation with high transmission loss around 18.9 dB over frequency range of 100–6300 Hz [33]. A work by Orfali conclude that the sound transmissions loss of polyurethane can be improved with addition of SiO nano-powder and carbon nanotube [34]. Application of acoustic metamaterials has been proposed to be a solution for controlling sound waves and mitigating noise propagation [35]. By using a composite porous metamaterial (CPM) made of arranged porous polyurethane sponge with embedded multi-layer I-plates, Gao et al. concluded that the sound absorption of porous polyurethane sponge significantly improved by doubled the mechanism of local acoustic energy dissipation of the I-plate and slow wave cancelation inside the structure [36].

Most research in the application of palm oil waste as acoustic materials still focused on using thick padding or insulation specimen. Studies on acoustical properties of polyurethane were typically performed on thick polyurethane foam and less studies on the acoustic properties of thin elastomeric thermoplastic polyurethane were found. However, installation of thick acoustic material will not be practical in narrow and confined spaces such as the interior of a vehicle. Therefore, it is considered that application of a thin sheet wall or mat as insulating material shall be more practical for the narrow space. Sound barriers and sound absorbers such as panels, curtains, or partitions, are typically employed as solutions to reduce noise levels. Plastic sheet wall can be used as workspace partition in larger industrial workspace where it can be functioned as a boundary impedance that can alter the cavity sound pressure [37]. Moreover, sound dampening mats can be installed in several part of heavy equipment to reduce the engine noise emission into the equipment's operator compartment [38]. By considering utilization palm oil waste utilization as properties enhancing material to elastomeric thermoplastic polyurethane (TPU), this work is meant to investigate the effect of oil palm trunks dust (OPTD) loading to mechanical and acoustical properties of elastomeric thermoplastic polyurethane sheet.

2. Materials and methods

2.1. Materials

BASF Ellastollan B90A Thermoplastic Polyurethane (TPU) was used as polymer matrix. The sample was used as received in the form of pellets. Oil palm trunk dust (OPTD) was employed as filler. The oil palm trunk was obtained from local oil palm tree in Malacca, Malaysia and prior to fabrication of the composite samples, the oil palm trunk fiber was treated with alkali treatment. The fiber was soaked in 0.5 M NaOH for 30 min then washed several times with water. This process continued by drying out the treated fiber under sunlight. The alkali treatment shall split up the fiber bundles of plant fibers to release the individual fibers and smaller fiber particles with a higher aspect ratio and a rougher topography that enhances fiber/matrix interactions can be produced [39]. To ensure there is no water content in the fiber, the fiber then redried in an oven at 100 °C for 6 h. Finally, the dried trunk fiber was grinded to powder by a crusher machine followed by filtering it with a 40 μm mesh nylon filter installed in a vibration shaker to obtain a fine oil palm trunk dust as shown in Fig. 1(a). Fig. 1(b) shows the micrograph of the OPTD which show typical morphology of the OPTD with size of ±30 μm.

2.2. Sample preparation

To prepare the TPU composites sample, the OPTD was mixed with the TPU pellet by varying their weight ratio as shown in Table 1. The mixing process was conducted for 12 min by using Haake internal mixer where temperature was regulated at 190 °C. The mixture then crushed by using the plastic crusher machine to prepare composite pellets for compressive molding process. The composite pellets samples were compressed in a 30 cm × 30 cm molding by hot compressive method. The composite was pre-heated at 190 °C for 7 min then pressed at pressure of 95 kgf/cm^3 and temperature of 190 °C for 3 min. The process is then continued by cold-press process for 5 min to produce a 3-mm thick TPU composite sheet. The sample is then cut into a dog bone shape sample for tensile test and a circular sample of 34.5 mm diameter for sound insulation and sound absorption test. The fabricated samples for acoustic test are shown in Fig. 2 (a) to (e).

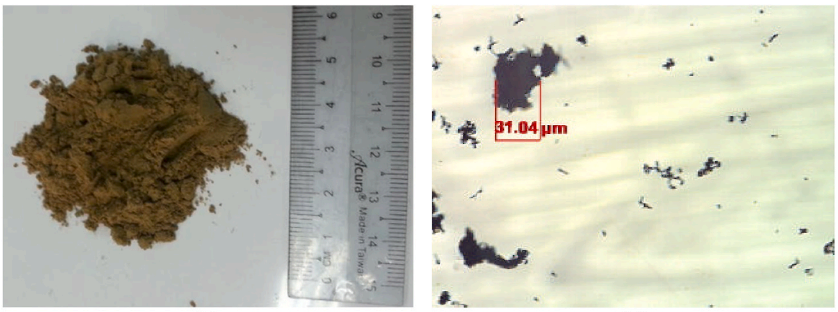
2.3. Physical and mechanical properties

Density is one of the important characteristics of typical acoustic materials. The density of the samples was measured according to ASTM D792-Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement by using Sartorius Digital Weighing Balance.

The modulus of elasticity of the fabricated samples was determined by using Instron 5960 Dual Column Testing Systems in accordance with ASTM D638-Standard Test Method for Tensile Properties of Plastics by employing the dog bone shape of type V sample. The tensile sample was made from fabricated composite sheet by a tensile test sample cutter. Fabricated tensile test sample is shown in Fig. 3 (a) and its dimension is shown in Fig. 3 (b). The test was repeated three times and the average of three readings is counted as the modulus of elasticity.

2.4. Microstructure

Microstructure study is an important element in understanding the interaction between the reinforcing dust with the TPU matrix in



(a) (b)

Fig. 1. Oil palm trunk dust (OPTD) sample. (a) OPTD sample after filtered, (b) micro-photograph of OPTD sample (100 × Mag.).

Table 1
Composition of thermoplastic polyurethane (TPU) matrix and oil palm trunk dust (OPTD) filler.

Sample	TPU (wt.%)	OPTD (wt%)
PU	100	0
0.9PU	90	10
0.8PU	80	20
0.7PU	70	30
0.6PU	60	40

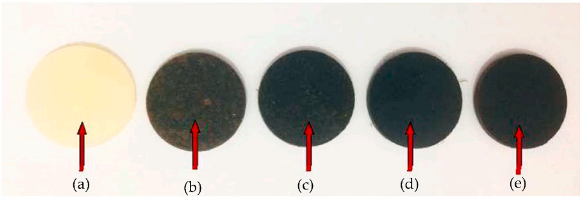


Fig. 2. Fabricated (a). PU, (b). 0.9 TPU, (c). 0.8TPU, (d). 0.7TPU, and (e). 0.6TPU samples.

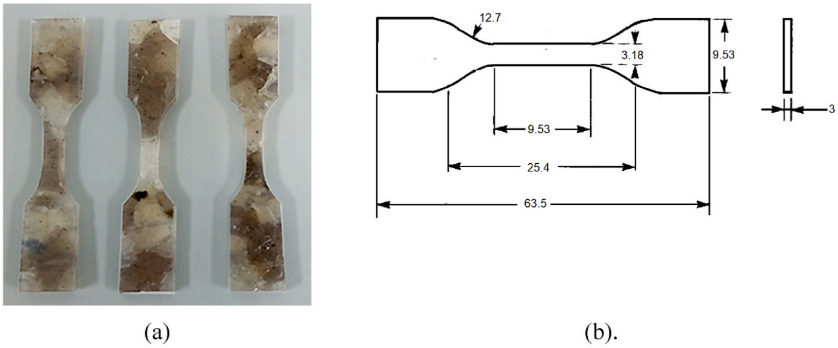


Fig. 3. Fabricated tensile test sample (a) and its relative dimension (b).

this work. The microstructure of the samples was examined by employing a Carl Zeiss EVO-50 Scanning Electron Microscope (SEM). Prior to observation, the sample was cut into 10 mm × 20 mm specimen. The microstructure of the sample was observed from the cross-sectional surface of the samples by using the secondary electron beam under magnification of 500 × .

2.5. Absorption coefficient measurement

Sound absorption coefficient measures how much sound energy is absorbed by an acoustic material (Fig. 4 (a)). It is defined as the ratio of absorbed sound energy, E_a, to incident energy, E_i, given by Eq. (1):

$$\alpha = \frac{E_a}{E_i} \tag{1}$$

In terms of the reflected sound energy, E_r, Eq. (1) can also be expressed as Eq. (2):

$$\alpha = 1 - \frac{E_r}{E_i} \tag{2}$$

The mechanism of sound absorption is frequency dependent. For porous and fibrous materials, the impinging sound vibrates the fibers and generates the frictional forces within the fibers. These forces convert sound energy into heat energy. The mechanism is also through the interaction of sound waves with the air spaces between the fibers. As sound waves pass through these air spaces, they cause the air molecules to vibrate, which generates heat due to molecular friction. This process is known as thermal conduction and contributes to the overall sound absorption of the material.

Another mechanism of sound absorption is by providing the air gap behind the acoustic panel against a rigid surface to create resonance as illustrated in Fig. 4. When the sound waves enter the air gap, they bounce back and forth between the material and the rigid surface. This bouncing back and forth creates resonance within the cavity, which increases the absorption of sound energy. This

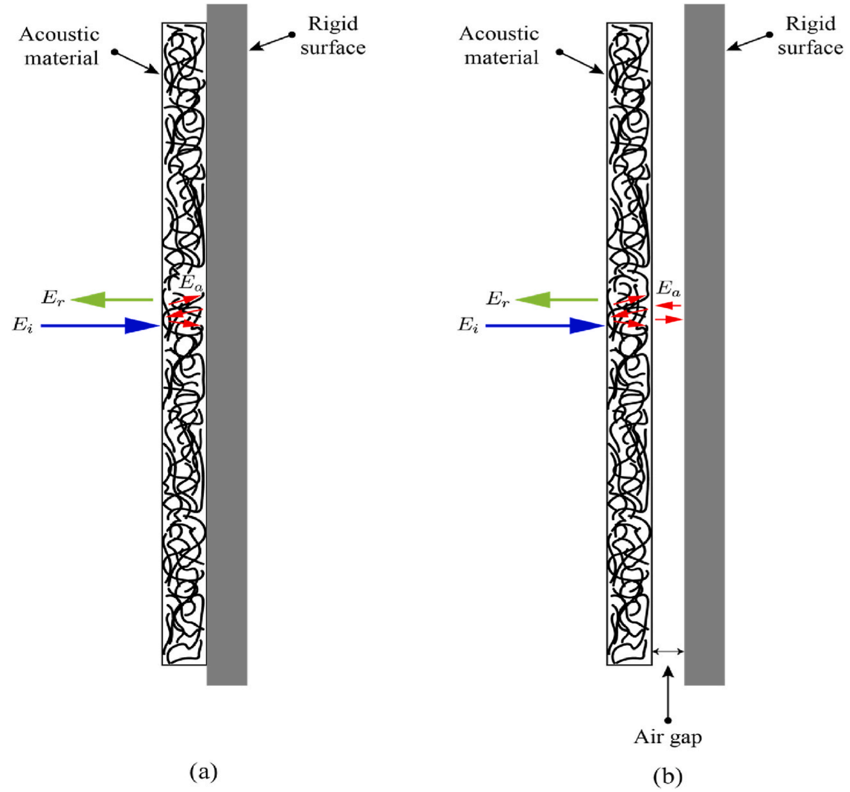


Fig. 4. Illustration of sound absorption mechanism in an acoustic material: (a) without air gap and (b) with air gap.

mechanism is known as cavity resonance. The illustration is shown in Fig. 4 (b). The latter mechanism is also used employing a thin panel to utilize the cavity resonance and the vibration of the panel to absorb the impinging sound energy.

There are two well-known methods for measuring sound absorption coefficient, namely the random incidence and normal incidence methods. The latter is the most convenient method as it only requires a small test sample fitted in an impedance tube. In this work, the measurement of the absorption coefficient was conducted using an impedance tube method according to ASTM E1050-19 [40]. A pair of half inch acoustic microphones were utilized to obtain the transfer function, H_{12} of the measured signals as the function of the reflection coefficient of the sample, *r,* as defined in Eq. (3) below:

$$r = \frac{H_{12} - H_i}{H_r - H_{12}} e^{2jk_0x_1} \tag{3}$$

where, H_i and H_r are incident and reflected transfer function respectively, $k_0 = 2\pi f_0 / c_0$ is a wavenumber with f_0 the sound frequency, c_0 the speed of sound and x_1 is the spacing between sample and the nearest microphone.

Eq. (4) is employed to calculate the normal incidence sound absorption by:

$$\alpha = 1 - |r|^2 \tag{4}$$

The schematic diagram of the measurement setup is shown in Fig. 5 (a) and the real experimental site is shown in Fig. 5 (b). The impedance tube system used was ACUPRO, using the transfer function method with two acoustic microphones as in Ref. [38]. The tube has inner diameter of $D = 34.9$ mm. The maximum valid frequency for the measurement is $f_u = 0.58c/D = 5.7$ kHz, where $c = 344$ m/s is the speed of sound. The lowest valid frequency is 50 Hz which depends on the performance of the signal analyzer. Prior to the measurement, the microphones were calibrated using a sound calibrator at 1 kHz of frequency and 114 dB sound intensity. In this work, the effect of air gap on the sound absorption is studied. The air gap with distance D between test sample and the backplate of the impedance tube was introduced and was varied by $D = 10$ mm, 20 mm and 30 mm, respectively.

2.6. Transmission loss measurement

Sound transmission loss (STL) is defined as the ability of material to block or attenuate sound. It is used as an indicator of sound energy loss as it passes through a partition. Higher STL indicates that more incident sound energy, E_i is blocked through the acoustic material. STL is considered useful particularly where sound isolation is crucial, for example to prevent high noise level from traffic to be transmitted into a building. The transmission coefficient is defined as:

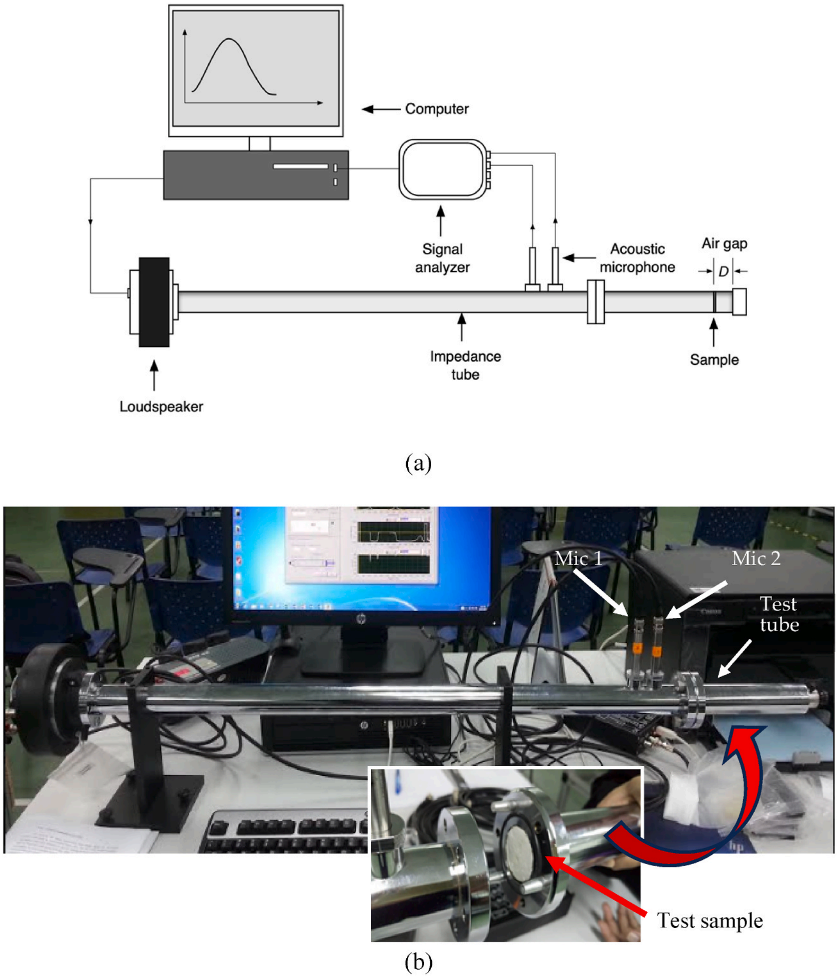


Fig. 5. (a) Schematic diagram of experiment set up, and (b) Photo of the experimental setup.

$$\tau = \frac{E_t}{E_i} \tag{5}$$

where E_t is the transmitted sound energy. The illustration is shown in Fig. 6. From the transmission coefficient in Eq. (5), the STL (in dB) can be calculated by Eq. (6) below:

$$\text{STL} = 10 \log \left| \frac{1}{\tau} \right| \tag{6}$$

The STL of the TPU composites was measured according to ASTM E−2611-09 standard [41] using an impedance tube test. The schematic diagram of the test is shown in Fig. 7(a) and the real experimental set up is shown in Fig. 7(b). The method involves two types of terminations when performing the test, including an anechoic termination to build up a transfer matrix to calculate the STL. In this testing, sound frequency in range of 100 Hz–5000 Hz was applied. The data acquisition and process were performed by ACUPRO system where one-third octave frequency band was used in the analysis.

3. Results and discussion

3.1. Physical properties

The density of fabricated TPU samples is shown in Fig. 8. The result shows that addition of the OPTD can slightly reduce the density of the TPU which the density reduced from 1.114 g/cm^3 to 1.008 g/cm^3. The elastomeric thermoplastic polyurethane typically has a higher density in cell structure in its single form and this can be the reason for the higher density of TPU sample than its composite sample. The diffusion of OPTD into the TPU matrix possibly interrupts intermolecular bonding of the basic TPU structure hence provide micro-pores in the composite's microstructure.

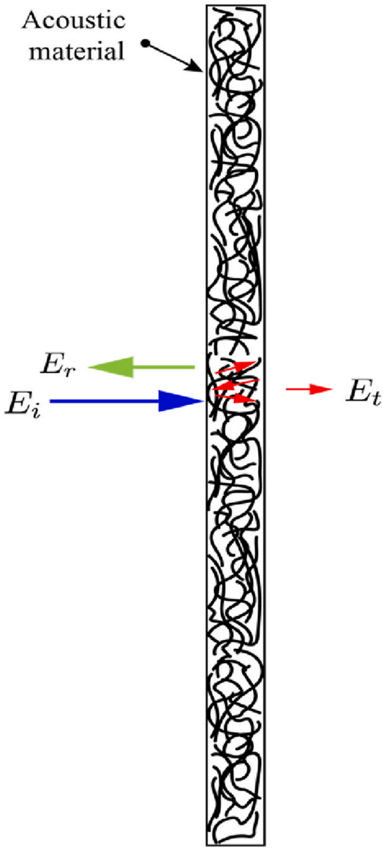


Fig. 6. Illustration of sound transmission through a partition.

3.2. Structural integrity

The mechanical properties of a material are related to its ability to withstand external forces and deformations. In the case of sound absorption, this can affect the way sound waves interact with the material and how much energy is dissipated. A material with higher stiffness may reflect more sound energy and have lower sound absorption properties, while a material with higher elasticity may absorb more sound energy and have higher sound absorption properties. Fig. 9 shows the typical stress-strain curve of the samples and Fig. 10 shows the typical feature of the sample before (Fig. 10(a)) and after testing (Fig. 10(b)). In addition, Fig. 11 shows the average modulus elasticity value relative to OPTD loading into TPU matrix. We can observe that the dust filler loading into the polymer matrix improves the mechanical properties of the TPU matrix. Young modulus of TPU improved with the loading of OPTD which the highest value observed at 20 wt% of OPTD loading (0.8TPU sample). The improvement of young modulus is considered related to diffusion of the dust particles into TPU matrix to compact the molecule structure of TPU and creating some reinforcement effect. In case of mechanical loading, the dispersed particles slow down the motion of dislocation while the matrix sustains the major portion of load. However, the modulus decreases after reaching the highest value which we believe is related to the lower mechanical integrity of the OPTD. Since more OPTD loaded into the matrix, the mechanical properties of the OPTD become dominant and consequently reduce the structural integrity of the composites. The result is in agreement with study by Yacoob et al. [42] when using oil palm trunk powder as reinforcement for polyurethane foam. They found that tensile strength of the composites was increased with the incremental of up to 20% the oil palm trunk powder content.

The results were also considered to be related to the alkali treatment of the fiber. The alkali treatment performed on the oil palm trunk can reduce fiber diameter to increase the aspect ratio and develop a rougher fiber surface topography to provide better fiber matrix interface adhesion and hence increase in mechanical properties [39]. In this work, grinding the chemically treated fiber into powder produced smaller particulate with smaller surface topography as well which is able to improve the molecular bonding between the matrix and the particles. A better bonding shall provide stronger mechanical properties for such bio-composite materials.

3.3. Surface morphology

Fig. 2 shows the normal view of the sample where we can observe that all samples possess solid and non-porous surface features with darkened color of the TPU in line with OPTD loading which related to diffusion and precipitation of carbonaceous OPTD. The

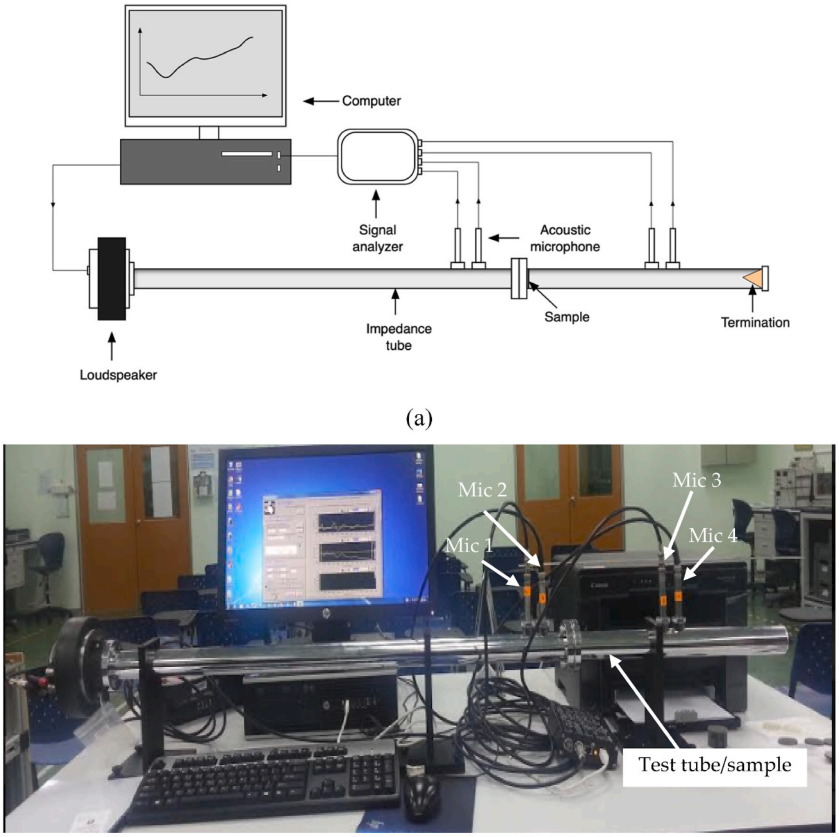


Fig. 7. (a) Schematic diagram and (b) Photo experimental setup for sound transmission loss.

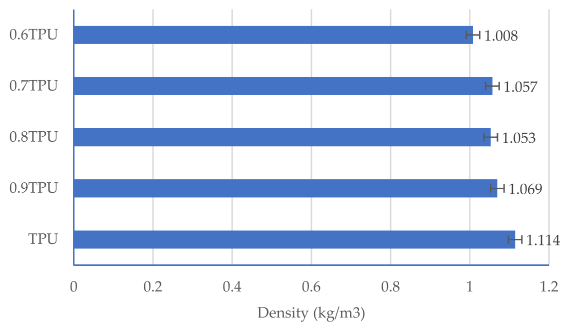


Fig. 8. Measured density of the samples.

carbonaceous OPTD was produced due to high mixing temperature (190 °C) during the sample preparation process. Fig. 12 shows SEM micrograph of the TPU samples from taken the cross-sectional area. It can be observed that the microstructure of the TPU sample is of very dense and solid feature and when the OPTD loaded into the TPU matrix, several micropores accompanied with tortuous structure can be observed. This formation of micropores is believed to be the reason for reduction of the TPU density with incremental of OPTD loading as shown in Fig. 8. Trace of precipitated OPTD can be observed from darkened area of the TPU matrix. Several micropores can be observed when 10 wt% OPTD loaded into the matrix (0.9TPU sample) as shown in Fig. 13. We also observed that OPTD are well precipitated into the TPU matrix which suggests good intermolecular bonding between the TPU and the OPTD. This feature explains the reason for enhancement of mechanical properties of the TPU as displayed in Fig. 11. The diffusion and precipitation of carbonaceous OPTD possibly disrupts intermolecular bonding of the basic TPU structure to give better bonding between dust filler and the TPU matrix and generate stronger structure.

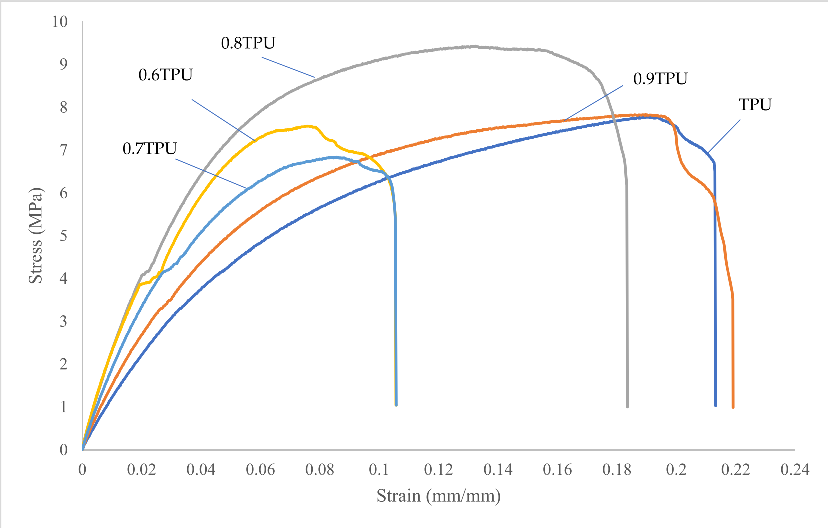


Fig. 9. Typical stress-strain curve obtained from tensile test.

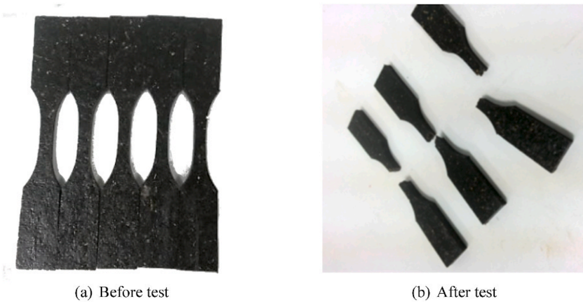


Fig. 10. The samples before and after the tensile test.

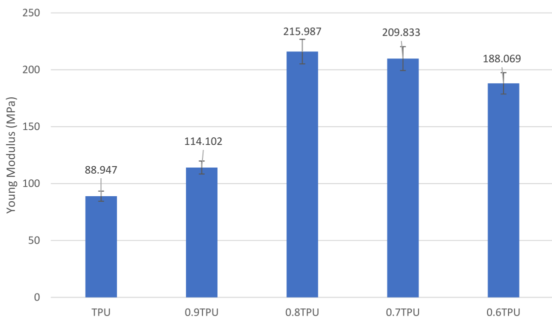


Fig. 11. Effect of OPTD loading to Young's Modulus of TPU.

In Fig. 14, more micropores and tortuous structures observed in the 0.8TPU sample accompany with well diffused OPTD into the TPU matrix. For the 0.7TPU samples (Fig. 15), smoother and longer tortuous features are observed and the micropores are thinner compared to 0.9TPU and 0.8 TPU samples. However, the microstructures of 0.6TPU (Fig. 16) show a larger micropores and tortuous structure which possibly lead to reduction of mechanical properties of this sample.

3.4. Sound absorption coefficient

Fig. 17 presents the measured sound absorption coefficient (SAC) of the samples. The sound absorption coefficient at frequency of 500–2000 Hz are showing higher absorption compared to other researcher work which using compacted oil palm wood particles

Fig. 12. Micrograph of TPU sample (500 ×).

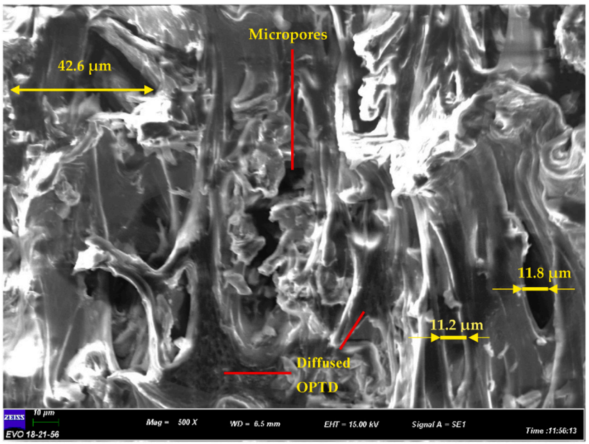


Fig. 13. Micrograph of the 0.9TPU sample (500 ×).

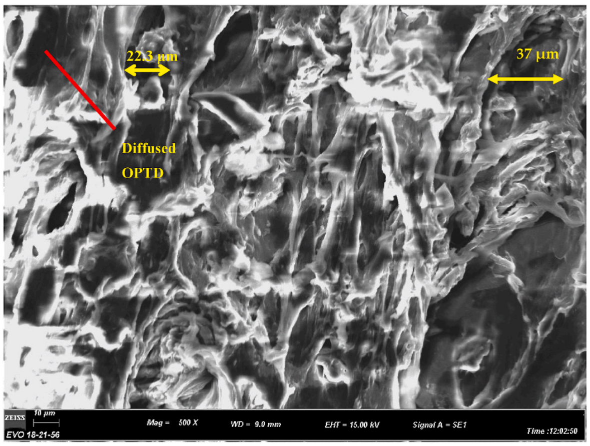


Fig. 14. Microstructure of 0.8TPU sample (500 ×).

without binder [43]. Furthermore, the effect of sound absorption of our sample appears above 3 kHz for all samples. This appearance is believed to be related to the thin thickness feature of the samples, where the long wavelength (greater than the thickness) at the low frequency is not effectively absorbed by any acoustic materials. Moreover, the results suggest that there is a mechanism of sound

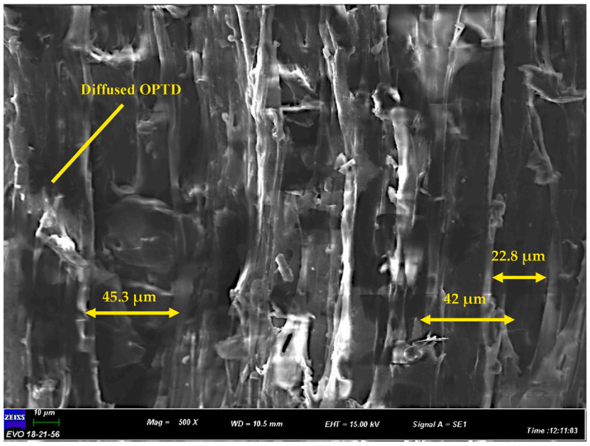


Fig. 15. Microstructure of 0.7TPU sample (500×).

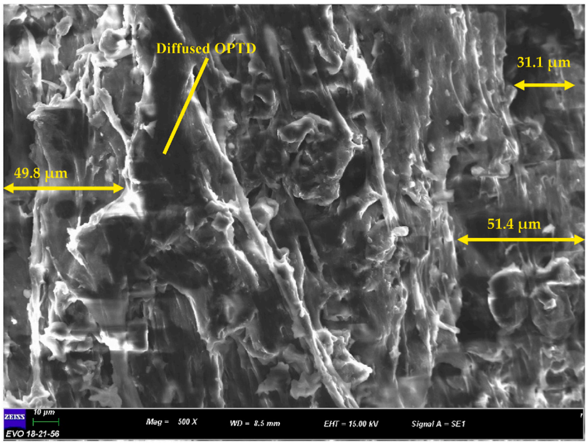


Fig. 16. Microstructure of 0.6TPU sample (500×).

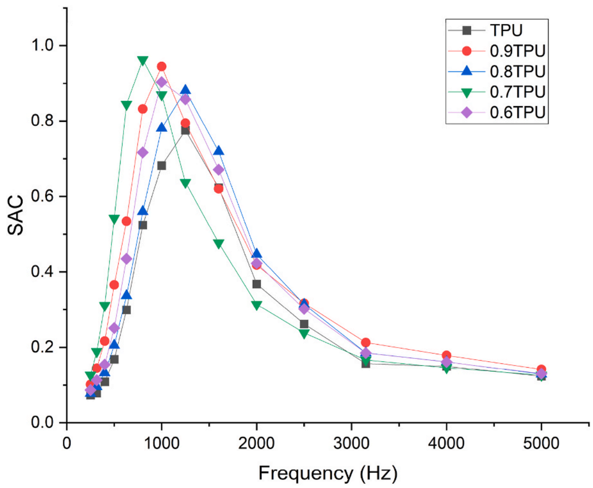


Fig. 17. Effect of the OPTD loading on the sound absorption coefficient (SAC) of TPU (without air gap).

absorption above 3 kHz which considered to be related to the formation of porosity and tortuosity inside the sample [10]. In a particulate-filled polymer composite, the reflection, scatter, refraction, and diffraction of the sound wave will be taken place due to the difference between the polymer matrix density and filler density. This can be lead to increasing of the sound wave propagation route and sound energy absorption [44]. Above 3 kHz, it can be seen that the absorption is variably changed with the OTP loading, although it is difficult to observe their linearity relationship.

Figs. 18–22 present the measured SAC when the samples are located against a rigid surface with an air gap. The general trend of SAC can be observed to have an absorption peak at certain frequency depending on the air gap. Since the samples have no holes, the sound transmits through the panel and then traps in the gap. The air inside the gap acts like a spring, and the vibrating portion of the panel is determined by the amount of mass around the center of the sample moves back and forth. This portion resembles the vibration of the first mode of a drum. Both parameters, spring and mass, then define the resonant frequency indicated by the peak absorption coefficient in the measured results. As seen in Figs. 18–22, by increasing the air gap, which is lowering the air stiffness, the absorption peak shifts to lower frequency. However, it is of interest to observe that the level of SAC improves when the OPTD load is introduced. The peaks of SAC are 0.8 for the TPU without OPTD (Fig. 18), but with the OPTD loading, the peaks can be seen to increase above 0.9. Addition of air gap typically performed as alternative to increasing the material thickness [45]. Sound absorption is principally caused by viscous dissipation which related to velocity of air through the pores of material, so when the material bonded to a hard wall, the sound absorption declined rapidly at lower frequency since particle velocity at the wall is zero. When the air gap exists, the particle velocity at the rear face of the material oscillates and reaches maximum value at the quarter wavelength of lower frequency range to increase the absorption. The formation of micropores as shown in Figs. 13–16 increases the viscous friction in the inner surface which then increases the peak of sound absorption. This can be further verified by measuring the air flow resistivity of the samples later. The peak frequency for each air gap has almost no effect with the OPTD loading.

3.5. Sound transmission loses

Sound transmission loss (STL) is the measure of reduction in sound energy (expressed in dB) from one side to the other side of a room which occurs when sound waves pass through a partition. Thus, the greater the value of STL, the better the partition at blocking the sound waves.

Fig. 23 shows the effect of OPTD loading on the measured STL. The effect of TPU loading on STL is observed on the mass-controlled region between 1 and 3 kHz where the STL increases in frequency by 6 dB per octave (the slope is 6 dB from 1 kHz to 2 kHz). In this frequency range, the STL strongly depends on the mass of the TPU. Thus, the highest STL is observed at TPU sheet without OPTD loading (the highest density) and the lowest STL is for 0.6TPU (the lowest density). As shown in Fig. 8, because 0.7TPU has greater density than that of 0.9TPU, hence it has greater STL.

4. Conclusions

The effect of oil palm trunks dust (OPTD) on mechanical and acoustical properties of thermoplastic polyurethane (TPU) sheet has been investigated in this work. By varying the OPTD loading in the range of 10–40 wt% into TPU matrix, several conclusions drawn in this work:

1. The density of the TPU matrix to gradually reduces from 1.114 g/cm3 to 1.008 gr/cm3 by the increasing OPTD content.
2. The Young's modulus is increased from 94 MPa up to 215 MPa as the OPTD loading increases.

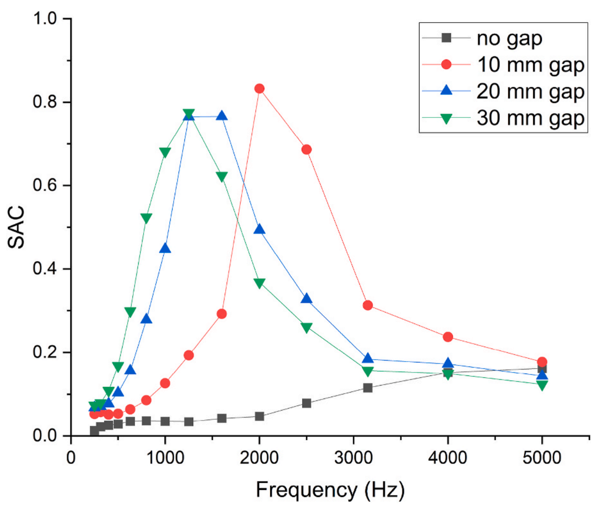


Fig. 18. Effect of air gap to the sound absorption coefficient of the TPU samples.

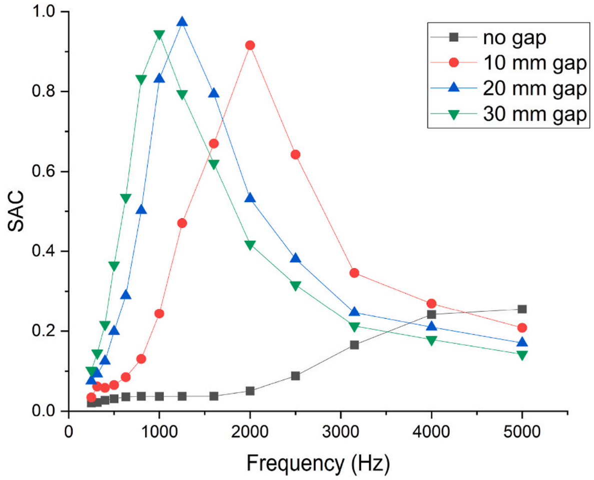


Fig. 19. Effect of air gap to the sound absorption coefficient of the 0.9TPU samples.

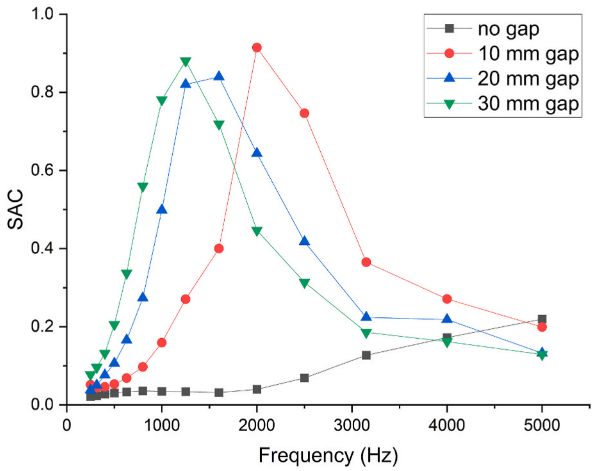


Fig. 20. Effect of air gap to the sound absorption coefficient of the 0.8TPU samples.

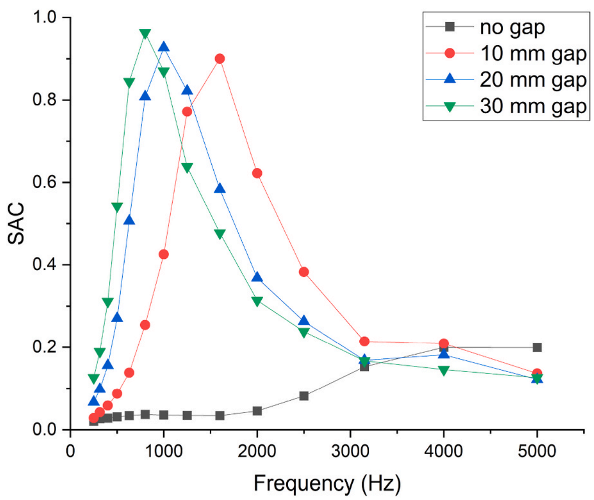


Fig. 21. Effect of air gap to the sound absorption coefficient of the 0.7TPU samples.

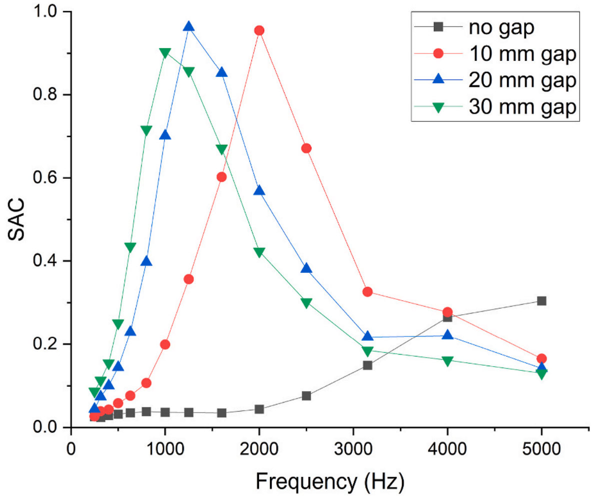


Fig. 22. Effect of air gap to the sound absorption coefficient of the 0.6TPU samples.

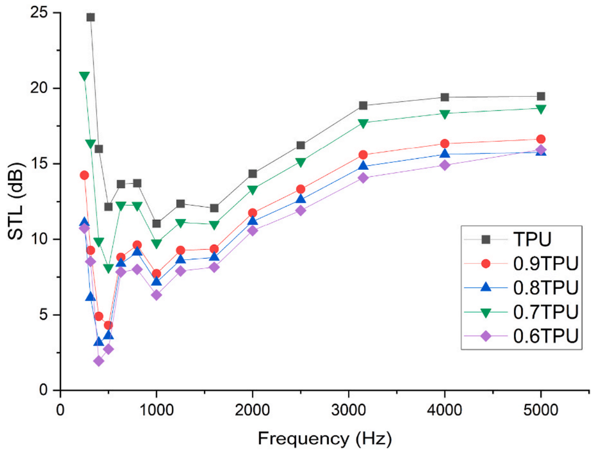


Fig. 23. Effect of OPTD loading on sound transmission loss (STL) of the test samples.

3. The considerable effect of OPTD loading on the sound absorption coefficient (SAC) is observed when the test sample is placed against a rigid wall with an air gap. The peaks of SAC are 0.8 for the TPU without OPTD, but with the OPTD loading, the peaks can reach above 0.9. This improvement is due to the formation of micropores as the OPTD is increased in the composite.
4. The OPTD loading appears to reduce the sound transmission loss (STL) as it reduces the density. Thus, as the proposed composite has potential application for sound absorber, care must be taken to apply the composite for sound insulation.
5. The thin sheet feature made of the fabricated composite sample can be used as sound absorber panel with air gap in narrow and confined space.

CRediT authorship contribution statement

Abdul Munir Hidayat Syah Lubis: Writing – original draft, Supervision, Methodology, Formal analysis, Conceptualization, Resources, Writing – review & editing, Investigation. **Azma Putra:** Writing – review & editing, Visualization, Methodology, Formal analysis. **Ahmad Shah Hizam Md Yasir:** Resources, Validation. **Irianto Irianto:** Validation, Writing – review & editing. **Safarudin Gazali Herawan:** Resources, Validation.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:Ahmad Shah Hizam Md Yasir reports article publishing charges was provided by Rabdan Academy. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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