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ACOUSTIC PROPERTY OF POLYURETHANE-TiO_2 COMPOSITE FOAMS

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Abstract

The acoustic property of polyurethane foam and polyurethane composite foams reinforced with different concentration (0wt%, 2wt%, 4wt% and 6wt %) of TiO_2 particles were investigated. The particle size of TiO_2 particle was analyzed by X-ray diffraction (XRD). The morphology of polyurethane composite foams was characterized by using optical microscopy. The acoustic property of polyurethane composite foams was measured using one microphone impedance tube method. The result show that polyurethane foam reinforced by TiO_2 particles have better the sound absorption properties than pure polyurethane foam and 6 wt% of TiO_2 particles reinforced in polyurethane composite foam obtain the maximum value of the sound absorption coefficient.

Keywords: polyurethane foam, TiO_2 particles, impedance tube, acoustic absorption coefficient

Introduction

Nowadays, rapid developments of modern industries and transportations lead to serious noise pollutions, which have significant adverse effects on the environment and personal health. Therefore, research and development of efficient and environmentally friendly sound absorbing materials is important **(**Yonghua W. et.al, 2013**).**The sound absorbing material is one of the major requirements for human comfort today, especially in automobiles and manufacturing environment and it is the relationship between the acoustic energy that is absorbed by the material and the total incident impinging upon it.

Polymer-based foams are widely used in industry to benefit from their mechanical, electrical, thermal and acoustic properties. Polyurethane (PU) is one of the polymers with the largest and most versatile applications having the ability to easily change its properties by changing the chemical composition or adding filler reinforcement agents. It is commonly used in automotive

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industry as sound absorbing material (Yuvaraj L., Vijay G., and Jeyanthi S., 2016). Shuming et al. (Shuming C, 2014) improved the sound absorption ability of PU foams with addition of nano-silica, results showed that with increase of nano-silica content, the sound absorption ratio of PU/nano-silica foams increased over the entire frequency range. Ancuț a-Elena Tiuca (Anctua-Elena T. et.al, 2015) studied on acoustic properties improvement of rigid polyurethane closed-cell foam, by incorporating various quantities of textile waste into the matrix. It was observed that the composite materials obtained have better sound absorption properties compared to rigid polyurethane foam.

The sound absorption coefficient is measured by using the phenomenon of reflection of sound waves. Sound waves are generated within a medium and transmitted towards the test sample. By measuring the incident and reflected waves, reflection coefficient and the acoustic absorption coefficient can be calculated. There are three standard methods for determining the absorption coefficient which are Reverberation method, Standing Wave Ratio (SWR) method and Transfer function method. Standing wave ratio method and transfer function method are also called impedance tube method. (NireshJ et.al, 2016)

This study focuses on the studying of acoustic property of polyurethane foam with the different concentration of weight percentage (0wt%, 2wt%, 4wt% and 6wt%) of TiO_2 particles. First of all, the polyurethane foam was synthesized by free-rising method. And then, TiO_2 particles were added to the PU foam to make PU composite foam. The particles size of TiO_2 particle was analyzed by X-ray diffraction (XRD). After that, the morphology of polyurethane-TiO_2 composite foams has been characterized by optical microscopy. Finally, the acoustic property of Polyurethane-TiO_2 Composite foams was analyzed by using one microphone impedance tube method.

Design and Construction of Impedance Tube

The experimental setup includes computer, data acquisition board, power amplifier, a speaker and a 1/4inch electret condenser microphone is shown in Figure 1 and Figure 2.The one microphone impedance tube was designed for the frequency range 100 Hz to 2000 Hz. The tube was constructed using commercial circular PVC pipe with the thickness of the pipe close to 5% of the tube diameter (Kin Ming et al. 2005). The tube also had to be long enough to ensure the development of sound waves between the sound source and the sample. The interior section of the tube can be circular or rectangular but should be constant dimension from one end to another. The tube should be straight and its inside surface should be smooth, nonporous, and free from dust to maintain low sound attenuation. Length of the tube should be greater than the thrice the diameter of the tube (L>3d). The distance between the sample and microphone is should be greater than the half of the tube diameter for the flat sample surface. The sound source, speaker was fixed at one end of the pipe and the sample was attached at the left of the impedance tube. For measuring the incident and reflected waves, microphone is required to be positioned and be able to measure the sound pressure levels inside the tube. The sample with diameter equal to that of impedance tube was placed above the surface of the rigid plate which was in the sample holder. Temperature of the surrounding had to be maintained constant throughout the experiment (Rick et al. 2004 &Suhanek et al. 2005).

The speaker was connected to the AUDIO OUT channel of NI my DAQ. The sound wave from the speaker was guided through a straight pipe of PVC tube. The microphone was connected to the AUDIO IN channel of the NI my DAQ board which was programmed to be synchronized and had the sampling rate of 5.4 kHz. The speaker was driven by NI my DAQ as the signal generator and the microphone captured the standing wave which was the superposition of incident and reflected wave from the sample. The sample was placed vertically at the end of the straight pipe, backed by a rigid plate. The NI myDAQ was used for both signal generation to the speaker and data acquisition of the microphone output. Once the microphone response was recorded, the desired acoustic property is calculated in Matlab. In this research, material was analyzed at the frequency ranging from 100 Hz to 2600 Hz.

The sound pressure at any position in the tube can be written as

$$p = \frac{sink(l-x) - izcosk(l-x)}{coskl + izsinkl} i\rho c v_0 \tag{1}$$

The acoustic impedance can be calculated by the following equation

$$\mathrm{z} = \frac{\mathrm{p(x,\omega)coskl - i\rho cvsink(l-x)}}{\mathrm{\rho cvcosk(l-x) - ip(x,\omega)sinkl}} \tag{2}$$

The specific acoustic impedance ratio can be expressed as

$$\frac{Z}{\rho c} = \frac{\mathrm{p(x,\omega)coskl - i\rho cvsink(l-x)}}{\mathrm{\rho cvcosk(l-x) - ip(x,\omega)sinkl}} \tag{3}$$

$$Z = \rho c \frac{1+R}{1+R} \tag{4}$$

The reflection factor (R) can be solved as

$$R = \frac{\frac{Z}{\rho c} - 1}{\frac{Z}{\rho c} + 1} = \frac{\frac{\mathrm{p(x,\omega)coskl - i\rho cvsink(l-x)}}{\mathrm{\rho cvcosk(l-x) - ip(x,\omega)sinkl}} - 1}{\frac{\mathrm{p(x,\omega)coskl - i\rho cvsink(l-x)}}{\mathrm{\rho cvcosk(l-x) - ip(x,\omega)sinkl}} + 1} \tag{5}$$

where l is the length of the tube, x is the distance between sample and microphone, ρ is the air density and c is the velocity of sound.

The sound absorption coefficient (α) can be calculated by the following

$$\alpha = 1 - \left| \frac{\frac{\mathrm{p(x,\omega)coskl - i\rho cvsink(l-x)}}{\mathrm{\rho cvcosk(l-x) - ip(x,\omega)sinkl}} - 1}{\frac{\mathrm{p(x,\omega)coskl - i\rho cvsink(l-x)}}{\mathrm{\rho cvcosk(l-x) - ip(x,\omega)sinkl}} + 1} \right|^2 \tag{6}$$

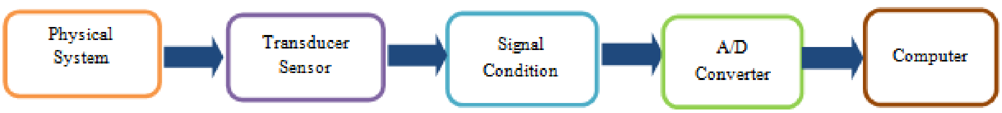


Figure1: (a) Block diagram of data acquisition

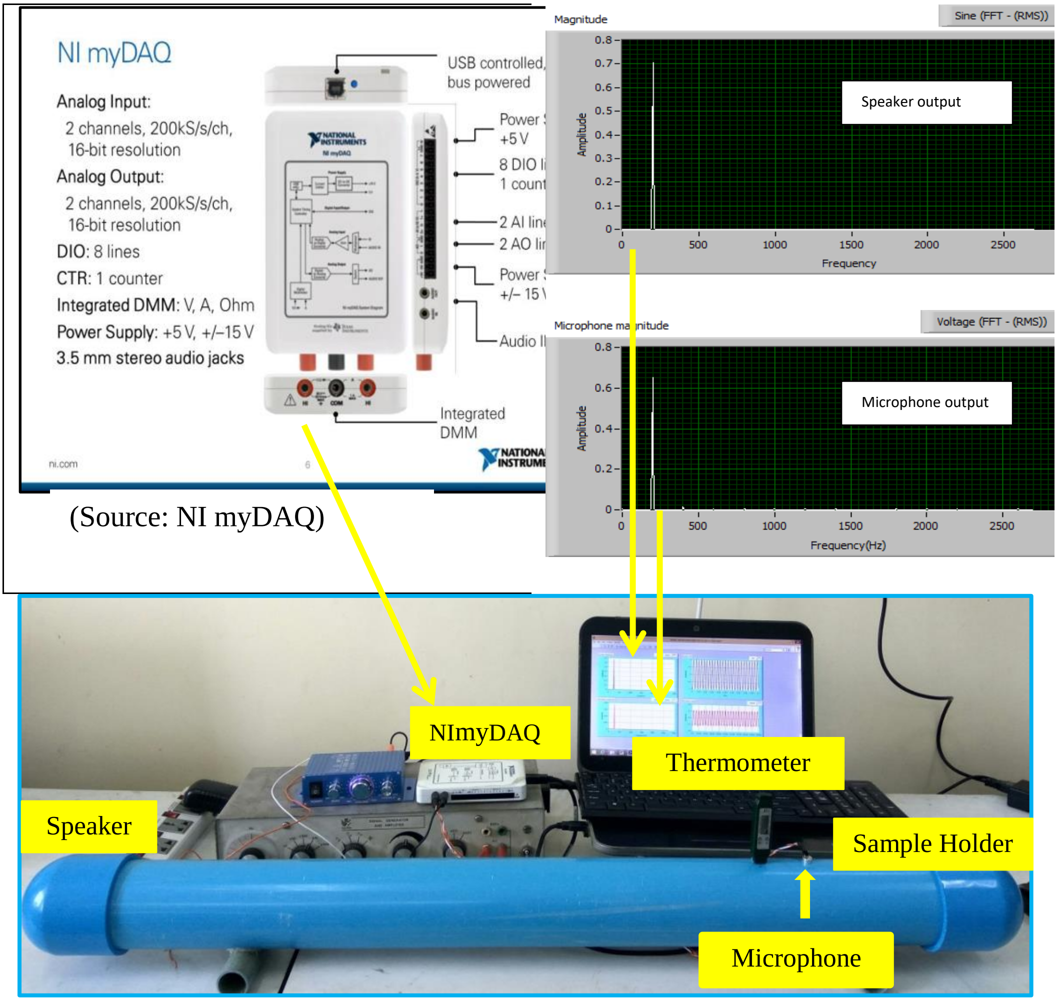


Figure 2:(a) Experimental setup of impedance tube

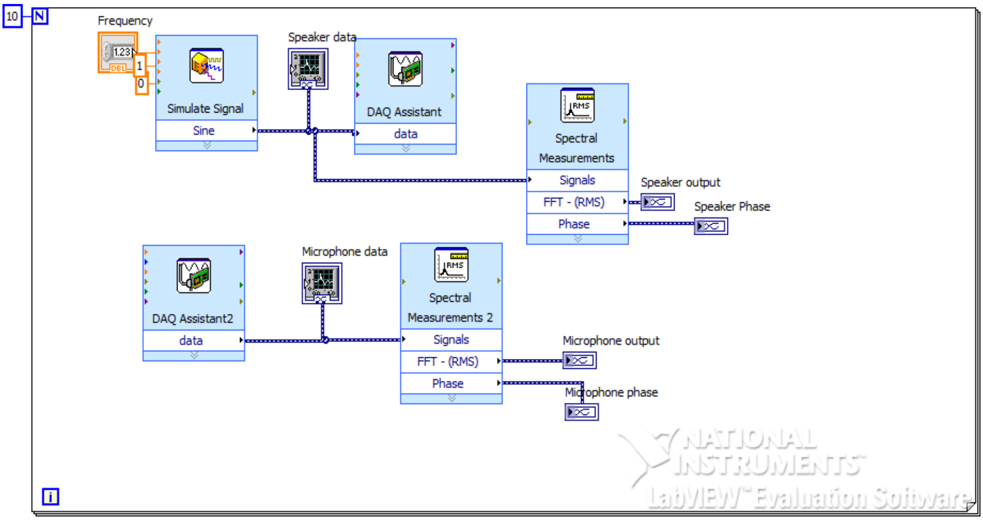


Figure 2: (b) Schematic diagram of data acquisition with LabVIEW

Synthesis of Polyurethane-TiO_2 Composite Foams

The polyol (polyether polyol, viscous yellow liquid, containing additives such as catalyst, blowing agent and surfactant) and isocyanate (Methylene diphenyl diisocyanate (MDI), dark blown liquid) were used for polyurethane (PU) foam formulation. Commercial TiO_2particles were used as filler in polyurethane foam. The PU composite foam with and without varied content of TiO_2particles were prepared by free-rising method. The PU foam was prepared by mixing the polyol and isocyanate at a ratio of 1:1. The proportion ratio of polyol, isocyanate and TiO_2 particles is shown in Table 1.

Table 1: Proportion of polyol, isocyanate and TiO_2

wt% of TiO_2	Polyol (g)	Isocyanate (g)	TiO_2particles(g)
0% TiO_2	15	15	0
2% TiO_2	15	15	0.6
4% TiO_2	15	15	1.2
6% TiO_2	15	15	1.8

To fabricate the polyurethane foam, the combination of isocyanate (part A) and polyol(part B) were measured. For the PU foam, different weight percentage of TiO_2 (0wt%,2wt%,4wt% and 6wt%) was first mixed with part B about 30 minutes to get homogeneous mixture by using magnetic stirrer hot plate 85-2 equipment. Figure 3 shows basic schematic of polyurethane-TiO_2 composite foams production. Then, part A was mixed with part B that also contains the filler and stirred together using a stir stick. During that mixing, exothermic reaction occurs. When the mixture started to get really warm to touch, the mixture was ready to place in the plastic mold (Anika et.al, 2017). A series of polyurethane foams with and without TiO_2 particles with loading fraction of 2wt%, 4wt% and 6wt% were also prepared by the above procedure. The formation of foam processing conditions is given below.

- Ratio (polyol to isocyanate) : 1:1
- Cream time :9 s
- Rise time :14 s
- Gel time :7 s

The mixed liquids were poured for foaming to a plastic mold with dimensions 5 cm × 5 cm × 5cm. After the foaming and curing process (at least 72 h at room temperature), samples were cut from the center of the block to characterize them. The flow chart of the process of polyurethane foam with different concentration of TiO_2particle is illustrated in Figure 4.

Figure 3: Schematic of polyurethane-TiO_2 composites foam production

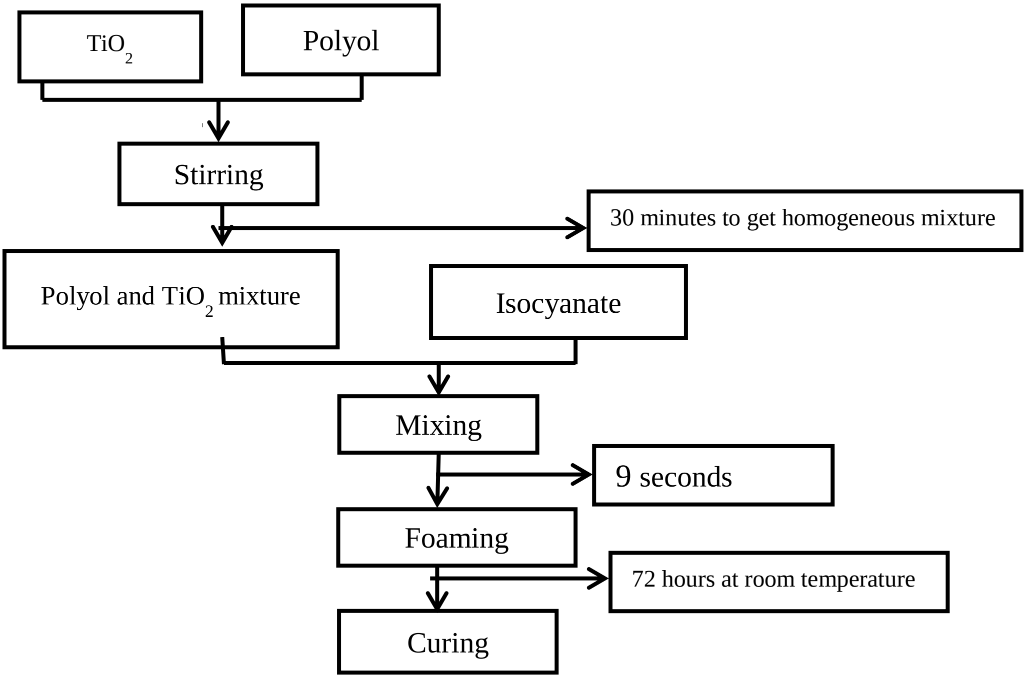


Figure 4: Process of production of polyurethane-TiO_2 composites foam

Results and Discussion

XRD Analysis of TiO_2 particles

The particle size of commercial TiO_2 particles was analyzed by Multiflex 2kW, Rigaku (Japan) X-ray diffraction(XRD). The X-ray diffraction pattern of the TiO_2 particles is shown in Figure 5. The intensity of XRD peaks of the sample reflects that the formed particles are crystalline. From this study, considering the peak at degrees, average particle size has been estimated by using Debye-Scherer formula. The average particle size of TiO_2 particle was about 372 nm.

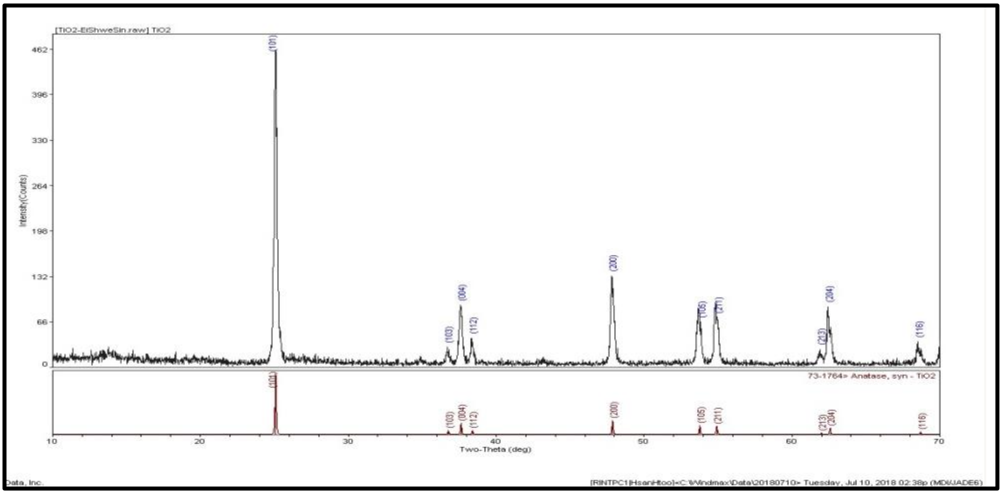
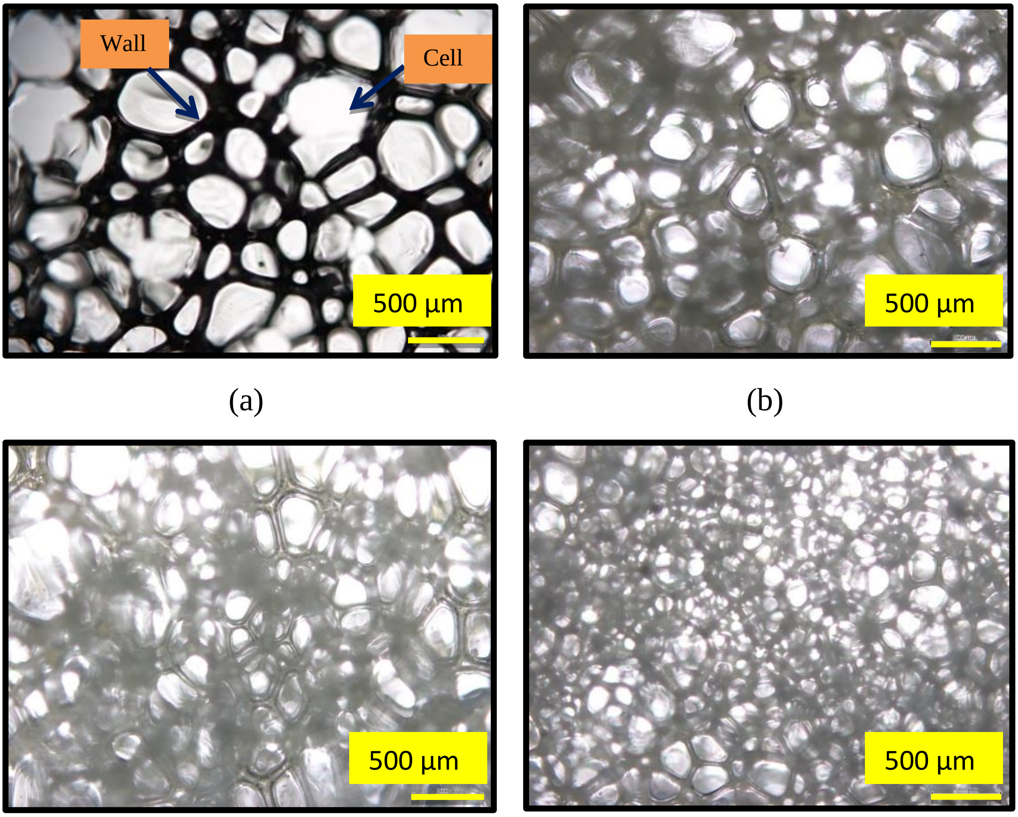


Figure 5: XRD analysis of TiO_2 particles

Morphological Structure of Polyurethane Foam Reinforced with TiO_2 Particles

The optical microscopy is used to analyze the surface morphology of polyurethane foams with different concentration (0wt%, 2wt%, 4wt% and 6wt%) of TiO_2particles which is shown in Figure 6. The samples were prepared as 1 mm ×1 mm ×1 mm sizes to see their surface with an optical microscopy. The cells (bubbles) appeared spherical and closed. The purpose of the optical microscopy analysis was to determine the size of the cells affected by the reinforced of TiO_2 in PU foams. The morphology of polyurethane- TiO_2 composite foams was evaluated by optical microscopy. The average cell size of the PU-TiO_2 composite foam was measured by using imageJ software. The average cell size of polyurethane foam with different concentration of TiO_2particles is shown in Table 2. According to the figure, it is observed that the cell size reduces when TiO_2 particles are added. The reason for the cell size reduction is due to TiO_2 particles act as nucleation agents and promote cell nucleation because of an effective decrease in the required energy for creating bubbles.



(a) (b)

(c) (d)

Figure 6: Morphology image of polyurethane –TiO_2 composite foams (a) pure PU foam (b) 2wt% PU-TiO_2 composite foam(c) 4wt% PU-TiO_2 composite foam(d) 6 wt.% PU-TiO_2 composite foam

Table 2 :Average cell size of polyurethane-TiO_2 composite foams

wt% of TiO_2	Average cell size (µm)
0%	325
2%	238
4%	174
6%	98

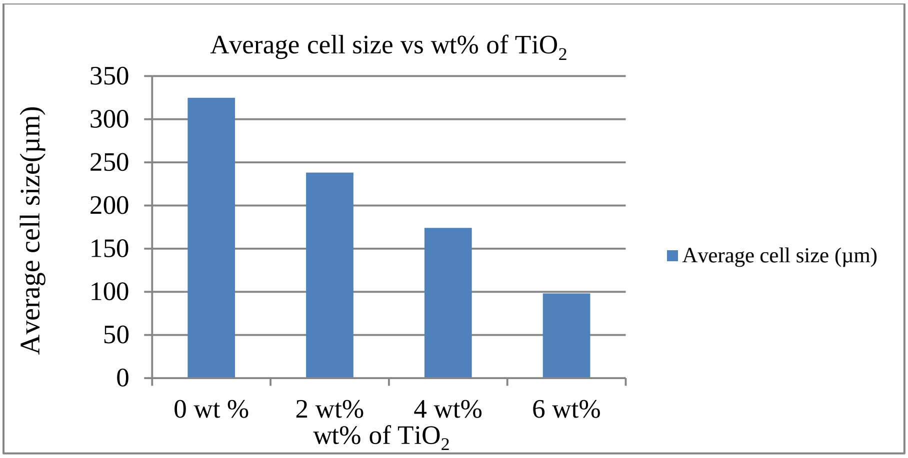


Figure 7: Average cell sizes of polyurethane-TiO_2 composite foams

Acoustic Absorption Coefficient Measurement

The acoustic absorption test was carried out using impedance tube with one fixed microphone apparatus.The signal generator and data acquisition were performed using National Instruments Labview. The NI my DAQ was used both for signal generation to the speaker and for data acquisition of the microphone output. Once the microphone response was recorded, Matlab was used to calculate the desired acoustic property. To validate the impedance tube setup constructed, the 6 mm thick polyurethane foam was measured and compared with the result of standard material such as glass which was 6 mm thick. This comparison result is shown in Figure 8.

The acoustic absorption coefficient of polyurethane foam with different concentration of TiO_2 particles is presented in Figure9.The comparison of estimated acoustic absorption coefficient of different concentration of TiO_2particles reinforced in polyurethane composite foams is presented in Figure 10. According to figure, it can observed that composite foams have better sound absorption properties compared to the pure polyurethane foam but the 6wt% polyurethane-TiO_2 composite foam has the best sound absorption property reaching a value of maximum 0.9 of sound absorption coefficient on the whole analyzed frequency ranges. This is due to the absorption coefficient of composite foams depending on the concentration of TiO_2 particles and frequency of the acoustic which strikes the surface of the composite foams.

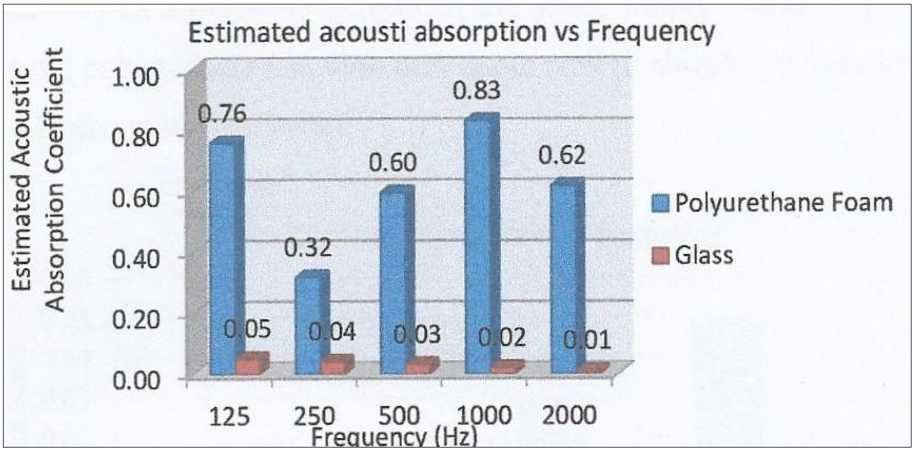


Figure 8: Comparison of estimated acoustic absorption coefficient of glass and Polyurethane foam

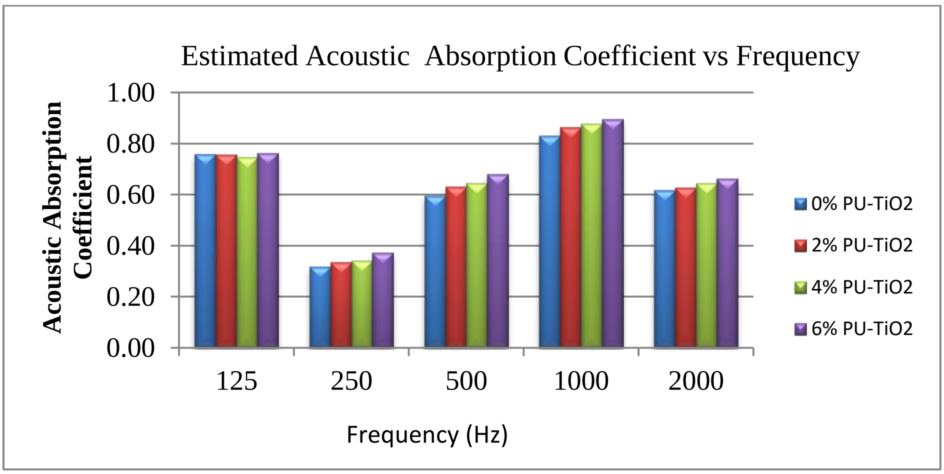


Figure 10: Comparison of acoustic absorption coefficient of different concentration of TiO_2 in polyurethane-TiO_2 composite foams

Noise Reduction Coefficient (NRC)

The noise reduction coefficient, NRC, is the arithmetic average of a material's sound absorption coefficients at 250 Hz, 500 Hz, 1000 Hz and 2000 Hz. The NRC was used to compare the acoustical property of different concentration of TiO_2 particles reinforced and non-reinforced in rigid polyurethane foam is illustrated in Figure 11. It can also observe that with the increase of concentration of TiO_2 particles percentage, the value of noise reduction coefficient (NRC) also increases. The 6wt% TiO_2 particles reinforced in polyurethane composite foam has the maximum NRC value of about 0.65 (it absorbs 65 percent of the sound hitting it and 35 percent bounces back), while rigid polyurethane foam has only about 0.59 (it absorbs 59 percent of the sound hitting it and 41 percent straight back).

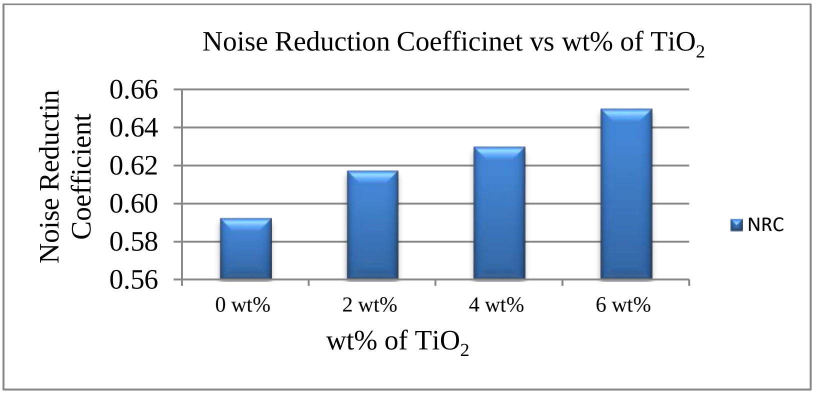


Figure 11: Comparison of noise reduction coefficient of different concentration of TiO_2 in polyurethane-TiO_2 composite foams

Conclusion

This study investigated an impedance tube with one fixed microphone which was used to determine the acoustic absorption coefficient of the polyurethane composites foam reinforced with different concentration (0wt%, 2wt%, 4wt% and 6wt%) of TiO_2 particles as sound absorbent materials. It was observed that the average cell size of polyurethane composite foams decreases when the concentration of TiO_2 particles increases. According to experimental result, the polyurethane foam and polyurethane-TiO_2 composite foams have approximately the same acoustic absorption coefficient at different frequency. The polyurethane-TiO_2 composite foams have more enhancement sound absorption property them pure polyurethane foam. Among them, 6wt% polyurethane composite foam has the best capacity to absorb noise, reaching a value of maximum 0.9 of sound absorption coefficient on the whole analyzed frequency ranges. With decreasing their cell size, the sound absorption coefficient of polyurethane composite foams increases. It can be concluded that foams with small cell size absorb sound better than the foams with large cell size. Therefore, the polyurethane-TiO_2 composite foams can be used not only in the indoor but also outdoor environment as sound absorbing material.

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