SOUNDPROOFING EFFECT OF PP/CLAY AND PP/CNT NANOCOMPOSITES

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1 Introduction

Noise generally refers to unwanted sound or sound pollution that can cause serious harm to the human body and the environment. Theories regarding the reduction of ambient noise from machinery and appliances have been recently developed [1–4]. One technique involves the application of sound-absorbing or insulating materials around noise sources [5–9]. Sound transmission loss (TL) must be maximized to minimize the transmitted energy. In this research, specimens made of polypropylene (PP)/clay and PP/CNT composites were fabricated and investigated to understand their soundproof insulation property. The soundproof effect of specimens was measured by sound TL through impedance tube method and investigated at different filler loads of original clay and CNT.

2 Theory of sound insulation

The sound-propagating characteristics of a space can be affected by the size and shape of the material within the space. The acoustic energy incident on a wall is reflected, lost, or transmitted. Reflectivity is the ratio of reflected acoustic energy to incident energy; acoustic absorption is the ratio of the sum of energy loss and transmitted energy to incident energy. The ratio of transmitted energy to incident energy is defined as acoustic transmissibility. The transmitted energy must be lowered in order to increase soundproofing efficiency. Therefore, energy loss and reflected energy must be maximized to minimize the transmitted energy. However, energy loss by sound absorption is limited by the thickness of the material [10]. So the most efficient way to increase soundproofing efficiency is to reflect the incident energy. This efficiency in turn depends on the mass, stiffness, homogeneity, and uniformity of the material. The sound insulating ability of a wall is measured in terms of the sound TL. TL can be defined as the difference between the sound power level of the incident wave and the transmitted sound power [11,12].

Sound TLs of specimens were measured by two serially located microphones attached to an impedance tube, as shown in Fig. 1. Test material is attached at the end of the impedance tube. The distances between the specimen's surfaces and two microphones are x_1 and x_2, respectively, and the distance between the two microphones is s.

When the impedance tube supplies a normal irregular sound signal through a speaker, the sound intensity $I_i(f)$ of the incident wave and the sound intensity $I_r(f)$ of the reflection wave are calculated by the sound transfer function $H_{12}(f)$ between points x_1 and x_2, and the magnetic spectral density function $S_{11}(f)$ at point x_1, and $S_{22}(f)$ at point x_2, as expressed in Equation (1) and (2).

$$I_i(f) = \frac{S_{11}(f)\begin{Bmatrix} 1 + |H_{12}(f)|^2 - 2R_e[H_{12}(f)]\cos k(x_1 - x_2) \\ +2\mathrm{Im}[H_{12}(f)]\sin k(x_1 - x_2) \end{Bmatrix}}{4\rho c \sin^2 k(x_1 - x_2)} \quad (1)$$

$$I_r(f) = \frac{S_{22}(f)\begin{Bmatrix} 1 + |H_{12}(f)|^2 - 2R_e[H_{12}(f)]\cos k(x_1 - x_2) \\ -2\mathrm{Im}[H_{12}(f)]\sin k(x_1 - x_2) \end{Bmatrix}}{4\rho c \sin^2 k(x_1 - x_2)} \quad (2)$$

Where c and f are the speed and frequency of sound in air, ρ is density of air, and $H_{12}(f)$ is the impulsive response corresponding to the combined incident and reflected waves evaluated between the two microphone locations. Im and Re are the imaginary and real parts, respectively, of the transfer function. Wave number k is $2\pi f/c$ and ρc expresses the air characteristic of impedance.

When a sound wave emitted from a test material does not return to the inside of the tube and the sound aborption ability of a specimen can be ignored, the transmission loss about the normal incidence signal can be given as Equation (3) from Equation (1) and (2). Here the TLs of sound insulation materials depend on the sound transfer function H_{12} (f) between two points.

$$\mathrm{TL}_{H_{12}}(f) = 10\log_{10}\left\{\frac{1 + |H_{12}(f)|^2 - 2R_e[H_{12}(f)]\cos ks + 2\mathrm{Im}[H_{12}(f)]\sin ks}{4\mathrm{Im}[H_{12}(f)]\sin ks}\right\} \quad (3)$$

3 Materials

Polymers have been filled with many types of fillers in order to replace metal and glass in reinforced composites which may be used in development of various products with high modulus, increased strength, heat resistance, decreased gas permeability and flammability. Polyethylene (PE) and PP are most commonly used polymers made so far at very economic level and their applicability further accelerates by their synthesis routes which provide freedom to tailor the end product as per desideratum. In this research, PP was produced by Samsung company with density 0.91 g/cm^3, yield tensile strength 360 kg/cm^2, melting point 210~250 ℃, and would be used as polymer matrix material.

Clay is a naturally occurring material composed primarily of fine-grained minerals. It shows a high level of plasticity over a wide range of water content, and hardens when dried or fired. In this research, clay was produced by Southern Clay Products with type Cloisite 15A, typical dry particle size ≤ 13 μm, moisture content <2%, density 1.66 g/cm^3, and would be used as the nanofiller to reinforce PP.

Carbon nanotubes (CNTs) are allotropes of carbon with a cylindrical nanostructure. These cylindrical carbon molecules exhibit extraordinary strength and unique electrical and thermal properties, making them potentially useful in many applications in nanotechnology, electronics, optics, and other fields of materials science. In this research, PP was produced by Hanwha Nanotech company with type MWCNT CM-95, density 1.8 g/cm^3, diameter 10~15 *nm*.

Xylene (400*ml*) was used as a solvent to dissolve PP and nanoclay. Maleic anhydride (0.1 *gram*) was served to accelerate the dissolution of clay into the PP matrix during the heating process thus the PP was functionalized with maleic anhydride in order to make it compatible with silicate layers by enhancing its surface energies.

4 Specimens fabrication

4.1 Dissolving process

Three types of specimens were made at 0.9, 4.8 and 6.5wt% of organically modified clay reinforced PP (100 *gram*) by solvent based techniques. And similarly, another three types of specimens were made at 0.1, 0.5 and 0.7wt% of CNT reinforced PP. Firstly, PP was dissolved in 400 *ml* xylene followed by mixing of desired percentage of modifier. Then, this mixture was heated on hot-plate with temperature 135 ℃ and stirring 300 *rpm* for about 2 hours. Finally, oven would be used to heat the precipitate taken out from the flask on hot-plate under 100 ℃ for 10hrs in order to get the materials which could be molded into square specimens through heating press machine. The specimens fabrication process was shown in Fig. 2.

4.2 Pressing and cutting process

The soundproof property was measured through the specimens with diameter 100 *mm* and thickness 3 *mm*. Firstly, the hot press machine was used to make specimens with side length 200 *mm* and thickness 3 *mm*. The temperature of hot press machine was set on 230 ℃ and the pressure was around 35 *MPa*. The heating time and curing time for specimen molding was 10 and 40 minutes respectively. And then, the laser cutting machine was used to cut square specimens into round specimens with diameter 100 *mm* which was very suitable to put in impedance tube without any sound leakage. The specimens were shown in Fig. 3.

5 Measurement of sound insulation

To measure sound TL of this PP/clay and PP/CNT composite specimens, four microphone impedance tube method was used. The amplitude of incident and transmitted sound waves was measured with four ¼-inch B&K 4196 microphones mounted on a B&K 4206 impedance tube. A B&K 2690 Nexus conditioning amplifier was used to amplify low signals. An HP 35670A frequency analyzer, connected to a computer through a GPIB interface, was used as the sound source and data acquisition device. The user interface was programmed in LabView v7.0. Fig. 4 showed each device and setup relationship of this measurement system. The measured sound TL results drawn in Fig. 5 showed that about 23 *dB* sound TL was increased for PP/clay(6.5wt%) composites compared with pure PP at sound frequency 560 *Hz* to 640 *Hz*. Fig. 6 showed that about 16 *dB* sound TL was increased for PP/CNT(0.7wt%) composites compared with pure PP at sound frequency 560 *Hz* to 640 *Hz*. And it showed that there was an upward tendency for sound TL when the percentage of clay and CNT reinforced PP was increased.

6 Conclusions

Specimens made of PP/clay and PP/CNT composites were fabricated and investigated for their soundproof property. Sound insulation efficiency of PP/clay and PP/CNT composites was increased with an increase in the percentage of clay and CNT to 6.5wt% and 0.7wt% respectively. And it showed that about 7 *dB* was increased for PP/clay(6.5wt%) composites compared with PP/CNT(0.7wt%) composites at sound frequency 560 *Hz* to 640 *Hz*. The addition of clay and CNT increases the viscoelasticity of the pure PP. The sound wave transmission and reflection through such mixed matrix are much more than only in pure PP matrix. That is why PP/clay and PP/CNT composites can increase the sound TL during given sound frequency. And the reason for more sound TL of PP/clay composite may be concluded that the interaction between sound wave and clay platelets are much larger than it between sound wave and CNT as clay platelets have 2-dimensional structure and CNT only has 1-dimensional structure. The sound wave reflection through clay platelets are much more times with more energy loss due to laminar structure of clay platelets than that of linear structure of CNT. The future work will be focus on the sound TL of PP/clay/CNT composites with different clay and CNT weight percentage together. It can be concluded that more sound TL will be lost due to more complicated matrix structure of clay and CNT reinforced PP composite. It depends on later microstructure observation by TEM to explain and confirm such conclusion. Moreover, mechanical property test on these PP/clay and PP/CNT specimens will be carried out in later days for real production and application.

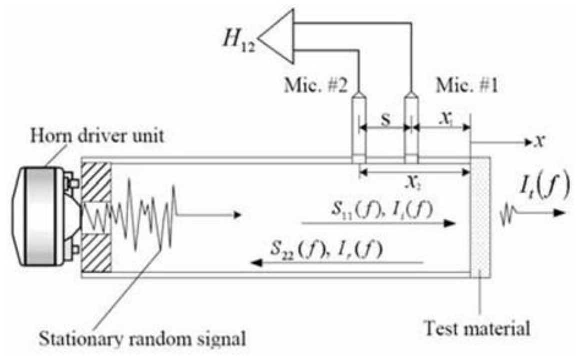

Fig. 1. Schematic of impedance tube

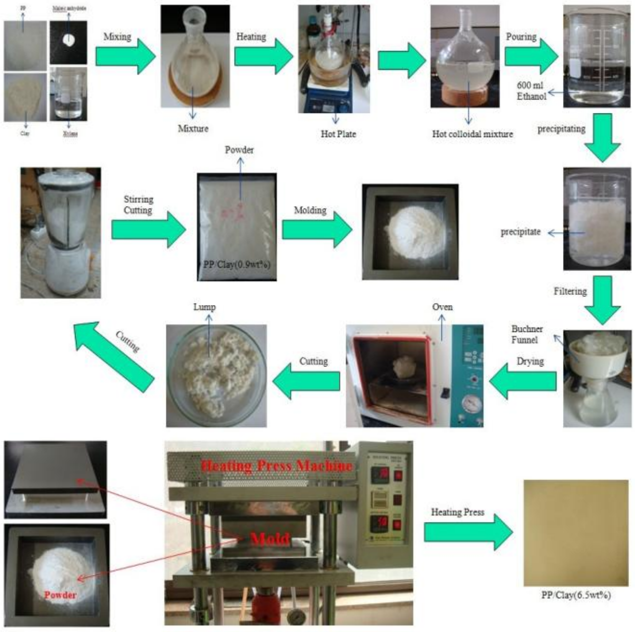

Fig. 2. Specimens fabrication process

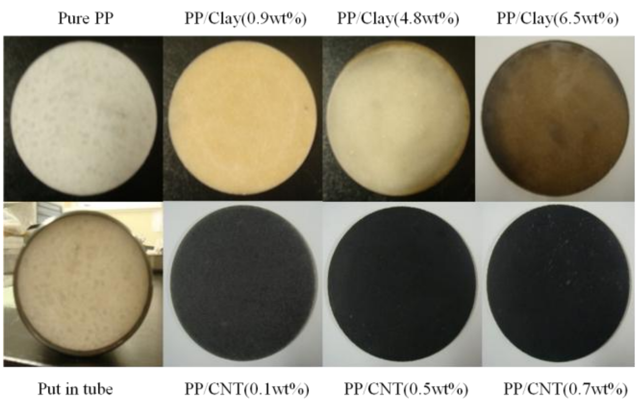

Fig. 3. PP/Clay and PP/CNT nanocomposite specimens

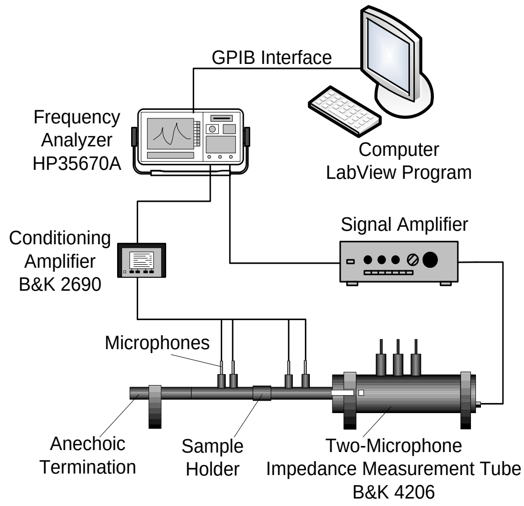

Fig. 4. Sound TL measurement system

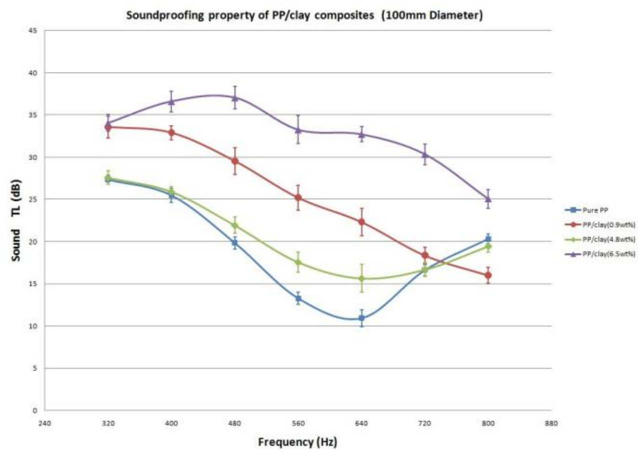

Fig. 5. Soundproofing property of PP/clay composites

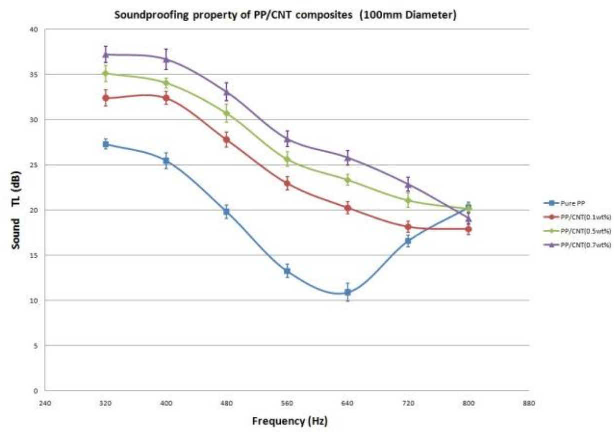

Fig. 6. Soundproofing property of PP/CNT composites

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