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# Evaluation on the manufacture of sound absorbent sandwich plank made of PET/TPU honeycomb grid/PU foam

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ABSTRACT

In this study, the sandwich plank consisted of 7D PET, TPU honeycomb grid, and PU foam. 7D PET and 4D low melting polyester fibers were needle-punched and thermal-treated so as to form the PET nonwoven layer. The PU foam was foamed with different density in the mold so to form the PU foam layer with different thickness. Finally, PET nonwoven layer, TPU honeycomb grid and PU foam layer comprised the PET/TPU/PU sandwich plank. The results indicated that the sound absorption coefficients of the specimens were over 0.93 on the frequencies ranging between 2000 and 4000 Hz.

*Keywords*： TPU honeycomb grid, PU foam, Sound absorption coefficient, Two-Microphone impedance tube

# INTRODUCTION

Since the industrial revolution in England in 18$^{th}$ century, technologies have progressed constantly. Exquisite mechanical products bring humans more pleasures; on the other hand, the rumbles of machines from factories represent the prosperity of the society and the modernization of a country. Though the rumbles caused by the industrial manufacture bring the times to the higher civilization and industrialization, they also jeopardize the workmen's hearing, cause the occupational disease and spoil the tranquility of the citizens [1]. Industrial textile is also one of the major goals in application for the current textile industry [2-11], technology to control noise is necessary. At present, most technologies applied in noise control are passive noise control, which can be divided into improving the mechanical structure around the noise source or placing the absorption materials and bafflers around the machine so as to change or block the noise transmission path and decrease the noise amount. For instance, when the noise waves pass through porous absorption materials, an energetic vibration is caused thus attenuating the noise energy. This simply means that the noise signal frequency which can be handled by passive noise control is dependent on the thickness of the absorption materials [12].

In 1952, the experiment conducted by Callaway and Ramer proved the significance to increase the density of the backing materials [13] while Attenborough (1983) discovered the sound characteristics of rigid fibrous materials and granular materials for sound absorption were both influenced by porosity, airflow resistance, curvature and foam factor [14]. Moreover, Olek reported in 2004 that four factors were related to the sound absorption of the road and they included the following: a) the porosity of the surface layer, b) airflow resistance of surface layer, c) the curvature of the pore connectivity, and d) the thickness of the porous layer. In particular, the porosity of the surface layer and the thickness of the porous layer had the most influence on the sound absorption of the road [15]. In 2008, Chu et al. explored the influence of the sound absorbent material with a side cover which vibrated to absorb the noise from the noise source. They concluded that sound waves were transmitted in the form of planar waves through the air medium and porous sound absorbent materials. The characteristic impendence and complex wave counts of the foam absorption materials were yielded using Two-chamber method. Based on the results of their research, when the vibration speed was positive, both the real characteristic impedance and image characteristic impedance increased. In contrast, when the vibration speed was negative, both of them decreased [16]. However, there has been little research exploring the material characters of fibrous plank. This study was conducted to explore the sound absorption characteristic of fibrous materials to manufacture an optimum sound absorption composite plank. This present study devised the composite sandwich plank with PET nonwoven layer, TPU honeycomb grid, and PU foam layer. PET nonwoven layer is for the sound waves to enter the interior with the aid of the air vibration. TPU honeycomb grid offered a space for PET nonwoven layer and PU foam layer to resonate and it also prevented the composite plank from deforming. PU foam layer has a closed porous structure and helped insulate the sound energy.



## EXPERIMENT

*Preparation of specimens*

In this study, the sandwich plank was composed of PET nonwoven layer (PET), TPU honeycomb grid (TPU), and PU foam layer (PU). 7D three dimensional crimp hollow polyester fiber (7D PET) and 4D low melting polyester fiber (low-Tm fiber) were provided by Far Eastern New Century Cooperation. First, the PET nonwoven layer was made of 7D PET and low-Tm fiber with a weight ratio as 7:3 and processed into PET nonwoven layer. Afterward a total of 6 to 10 laminates PET nonwoven were thermal treated in a mould at 150℃ for twenty minutes and then cooled at room temperature so as to form the 10-mm-PET nonwoven layer. 9 laminates were the optimum parameter for the PET nonwoven layer. Second, the thickness of the TPU honeycomb grid varied from 2 to 10 mm and 10 mm was the optimum manufacture parameter for the TPU honeycomb grid. Third, foam reagent A and hardener reagent B were blended in the volume ratio 1:1 and then placed in a mould to foam and harden for two days until the PU foam layer was formed. And the optimum thickness and density of the PU foam layer were 10 mm and 1.0 $kg/m^3$. Finally, we fabricated the PET nonwoven layer, the TPU honeycomb grid and the PU foam layer into the PET/TPU/PU sandwich plank with a thickness of 40 mm.

*Testing Method*

The test of sound absorption coefficient was according to ASTM E1050-07 employing Two-Microphone Impedance Tube. The test was carried out under the conditions: the relative humidity was 65±2 % and the room temperature was 20±1℃. Two-Microphone Impedance Tube Method is also called Transfer Function Method. Sample was placed at the opposite end to the sound source. The sound source produced white noise. The noise went through the sample and was reflected by the rigid wall. Two microphones in different positions within the impedance tube detect and collect the energy of the incident waves and reflected waves. The signal from each microphone system is connected to an individual channel of the analyzer (see Figures 1, 2)

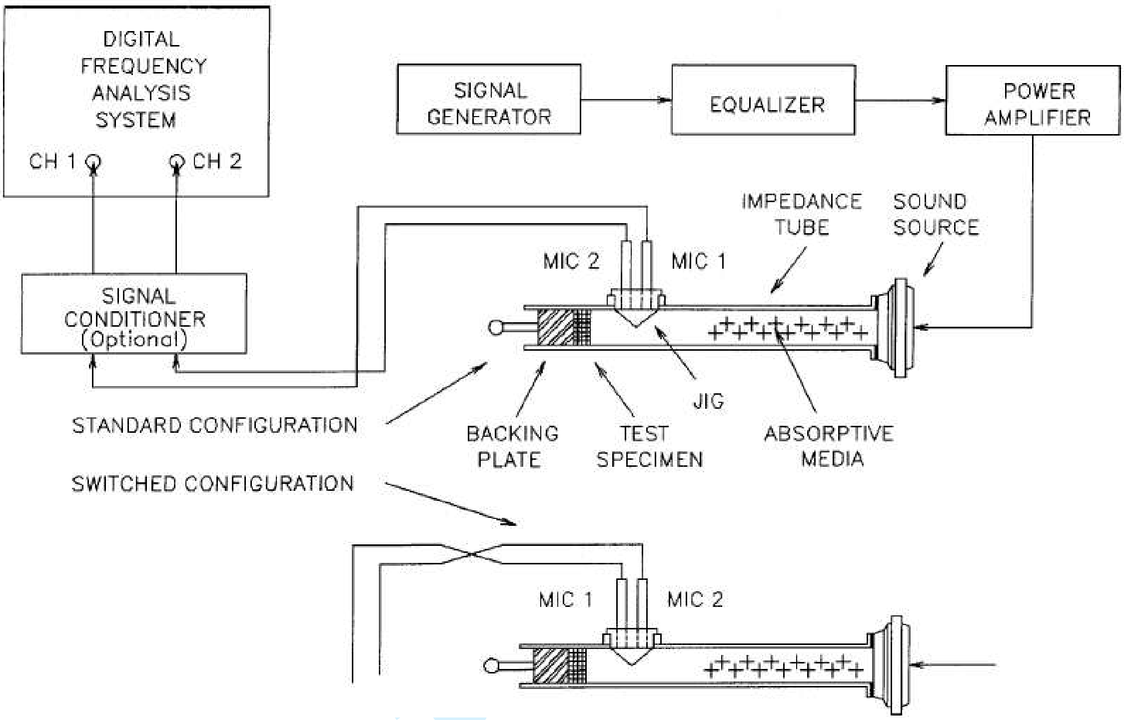



Figure 1 Apparatus and Instrumentation [17]

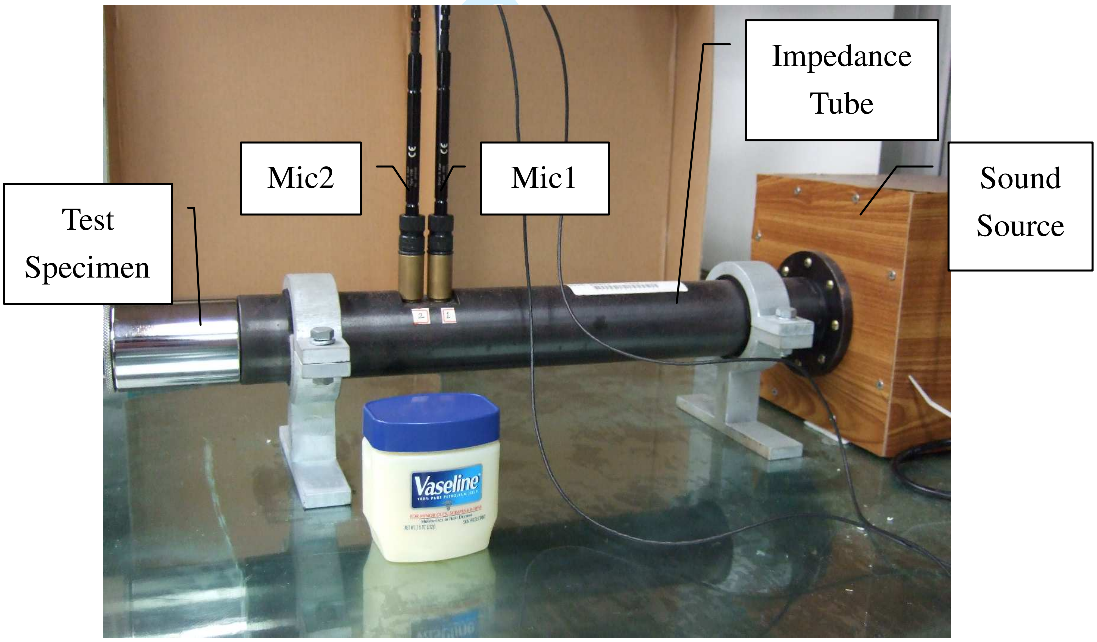



Figure 2 Apparatus of Two-Microphone Impedance Tube

## RESULTS AND DISCUSSION

The PET Nonwoven Layer

*The influences of the laminated counts of the PET nonwoven layer on the sound absorption coefficient of the PET nonwoven layer.*

The PET nonwoven layer was made of 7D PET and 4D low-Tm fibers with the weight ratio 7:3 first. The laminated counts of the PET nonwoven layer were from 6 to 10 but the thickness of the PET nonwoven layer was stationary as 10 mm. Figure 3 presents the sound absorption coefficient of the PET nonwoven layer at various frequencies. The results showed that the density of the PET nonwoven layer changed when PET nonwoven layers with different laminated counts were pressed into the same thickness. The PET nonwoven layer contained fewer pores with the increase of its density. When the laminated counts increased from 6 to 10, the average sound absorption coefficient was promoted with the increase of the nonwoven airflow resistance. 9-laminate PET nonwoven layer had the optimum density and optimum sound absorption. When the laminated counts were 10, the nonwoven airflow resistance was so high that the sound waves could not enter the interior with the aid of the air vibration. Hence, while abraded with the fibers, the sound waves failed in processing the viscous flow to abrade the sound energy. The sound absorption coefficient for 10-laminate PET nonwoven layer was not as good as that of 9-laminate one. Therefore, laminated counts of 9 was the optimum manufacture parameter for the PET nonwoven layer and the sound absorption coefficient was between 0.79 and 0.93 at the frequencies between 2000 and 4000 Hz. Figure 4 shows the illustration of the thermal bonding points and net structure of the PET nonwoven layer.

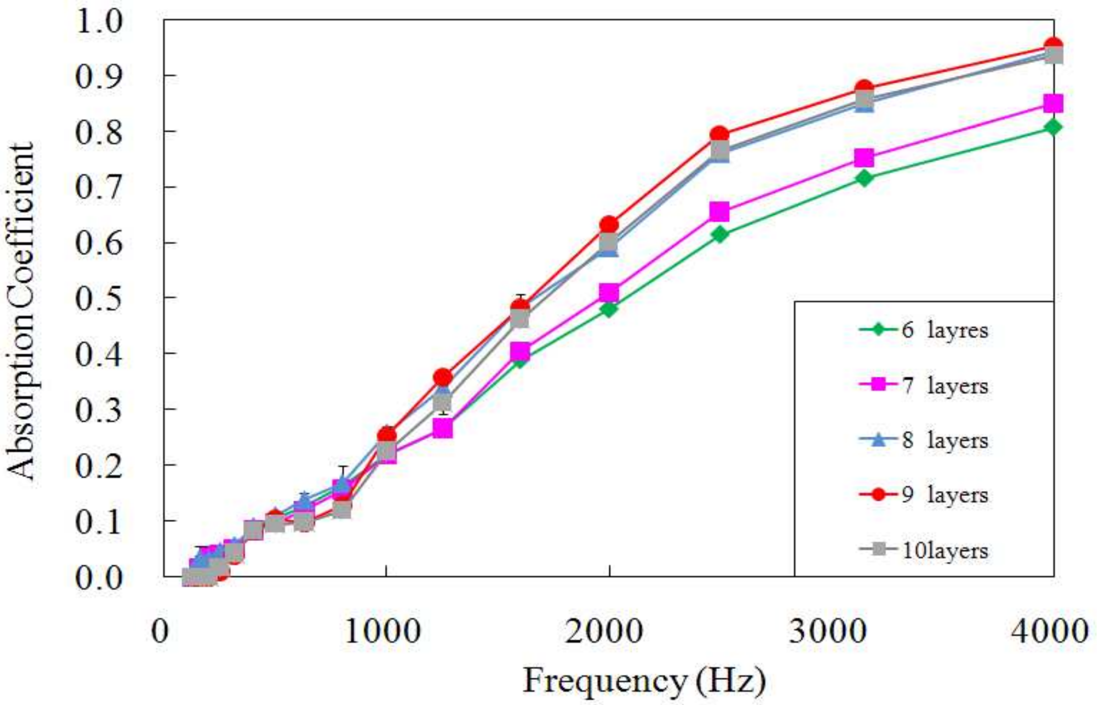



Figure 3 PET nonwoven layer is made of low-Tm fiber and 7D PET (3:7); with its thickness fixed as 10 mm. The laminated counts of the PET nonwoven layer are set as 6 to 10 laminates in order to determine their influences on the sound absorption coefficient of the PET nonwoven layer.

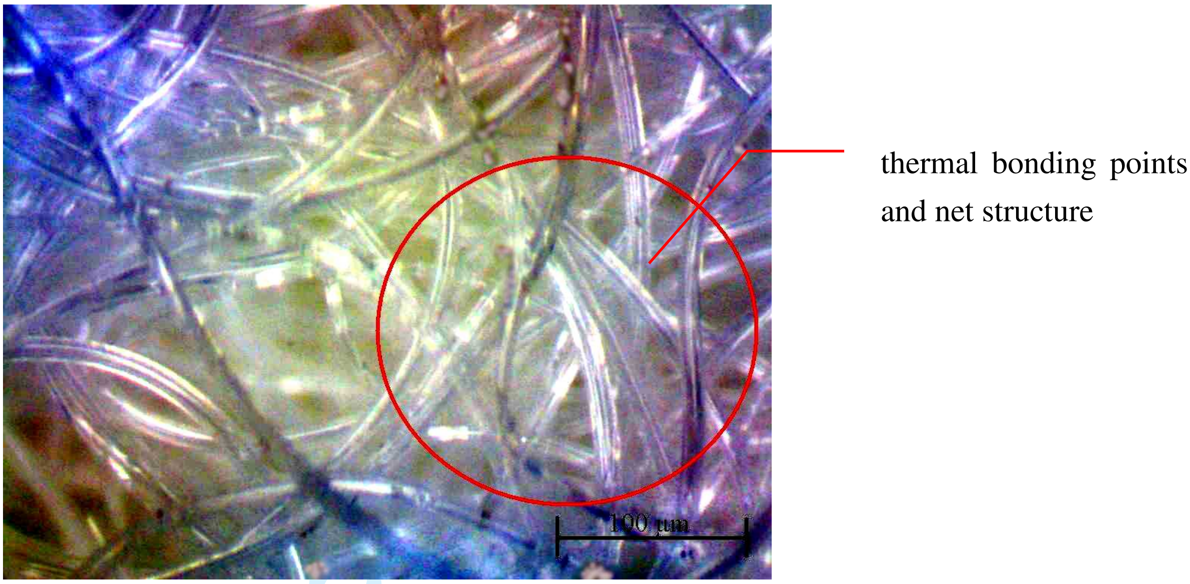



Figure 4 The illustration is taken with an optical microscope and shows the thermal bonding points and the net structure inside the PET nonwoven layer. The PET nonwoven layer contains 30 wt% of low-Tm fiber and 70 wt% of 7D PET.

*The influences of the weight ration of the 7D PET and low-Tm fiber on the sound absorption coefficient of the PET nonwoven layer*

Figure 5 shows the sound absorption coefficient of the PET nonwoven layer containing low-Tm fibers at 10 to 50 wt%. The thickness of the PET nonwoven layer was fixed as 10 mm and the laminated counts of the PET nonwoven layer were set as 9. When the low-Tm fiber received the thermal treatment, its surface melted and had net structure bond with the 7D PET. The structural complexity was heightened and had an influence on the sound absorption coefficient as shown in Figure 6. Compared to 8:2 or 9:1 (7D PET/low-Tm fiber), the PET nonwoven layer of 7:3 had more thermal bonding points jointing 7D PET and low-Tm fiber and the sound energy was abraded by the porous net structure. However, when the weight ratio was 6:4 or 5:5, there were fewer 7D PET and too many bonding points so the porous structure was blocked by the molten materials. As a result, the air mobility became worse and the sound absorption ability went down slightly. Therefore, the weight ratio of 7:3 (7D PET/low-Tm fiber) was the optimum manufacture parameter for the PET nonwoven layer; the sound absorption coefficient of the PET nonwoven layer was between 0.81 and 0.93 on the frequencies from 2000 to 4000 Hz.

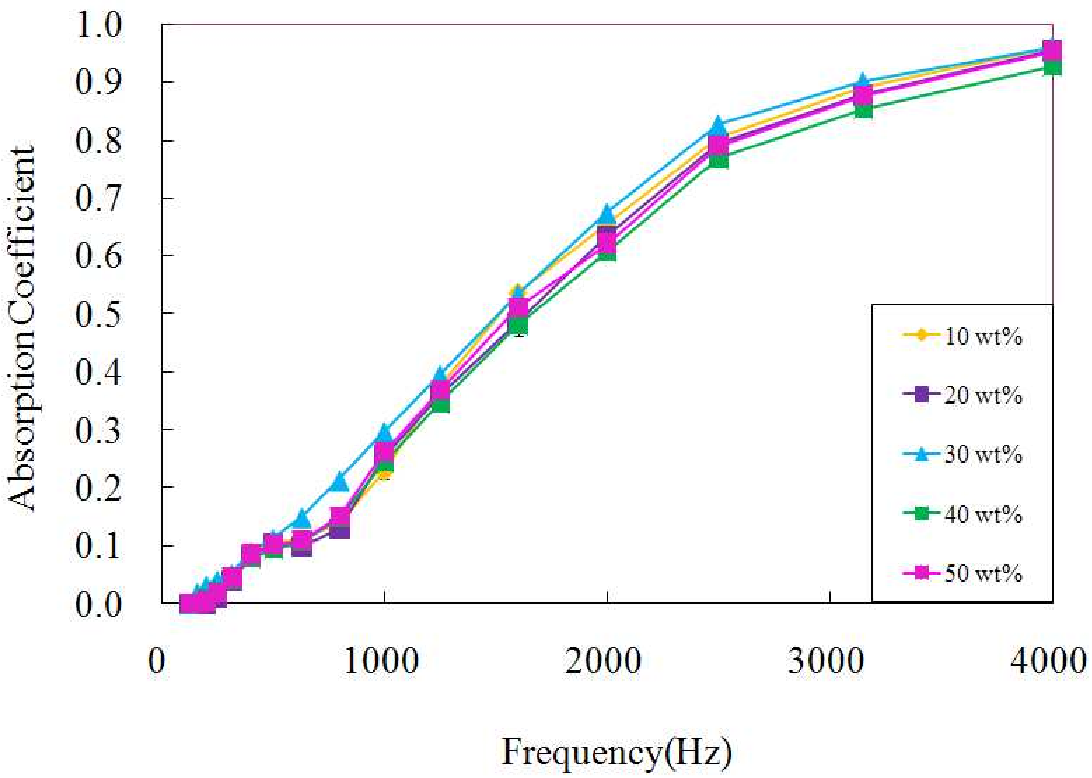
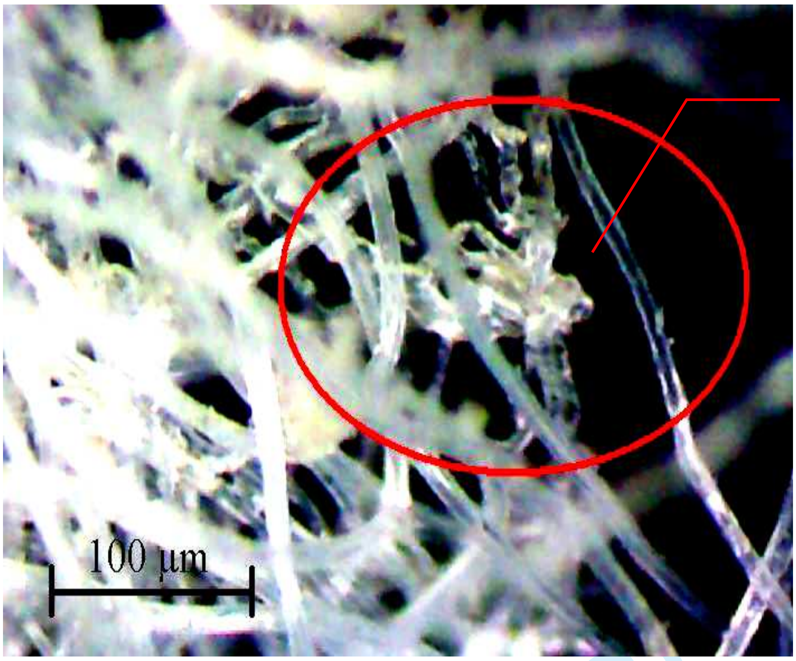


Figure 5 The PET nonwoven layer is made from 7D PET and low-Tm fiber. The thickness of the PET nonwoven layer is set as 10 mm and laminated counts are set as 9. The content of the low-Tm fiber is changed from 10 to 50 wt% in order to determine its influence on the sound absorption coefficient of the PET nonwoven layer




The surface of the low-Tm fiber melts and forms the thermal bonding points and net structure jointing the 7D PET and low-Tm fiber.

Figure 6 The thermal bonding points and net structure jointing 7D PET and low-Tm fiber are shown in the illustration taken by an optical microscope.

## The TPU Honeycomb Grid

We fabricated the PET/TPU/PU sandwich plank according to the manufacture parameters as follows. The thickness of the PET nonwoven layer is 10 mm; the thickness of the TPU honeycomb grid (TPU) varies from 2 to 10 mm; and the thickness and the density of the PU foam layer are 20 mm and 1.0 kg/m$^3$. TPU was equal to the air layer where the sound waves entered and it offered a space for PET nonwoven layer and PU foam layer to resonate. In addition, it could also substitute the porous material and offered the composite plank a certain elastic compression stress to prevent the composite plank from deforming. Figure 7 shows the sound absorption coefficient which becomes better with the thickness of the TPU and Figure 8 (a) and (b) show the structure of the optimum sandwich plank. The top layer was the PET nonwoven layer, the insert layer was the TPU honeycomb grid, and the bottom layer was the PU foam layer. 10 mm was the optimum parameter for the thickness of the TPU; the sound absorption coefficient fell on 0.88 to 0.94 on the frequencies between 2000 and 4000 Hz.

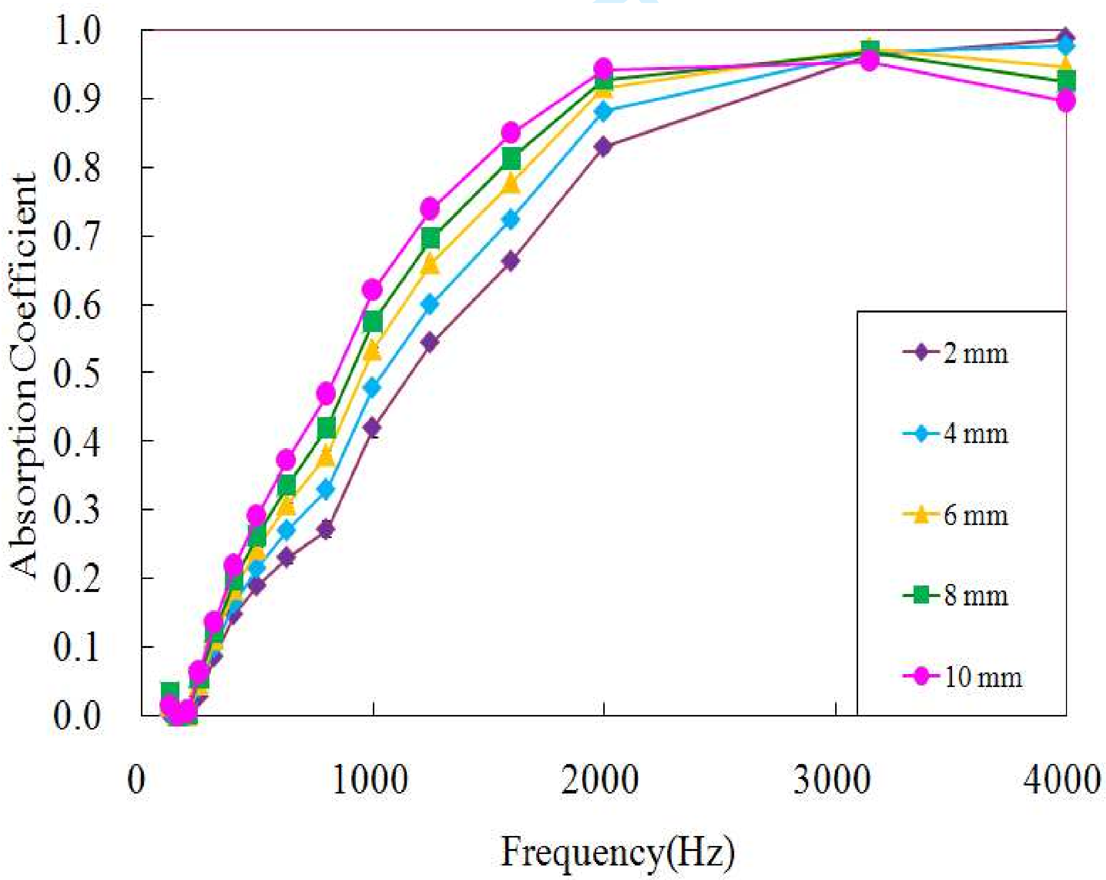
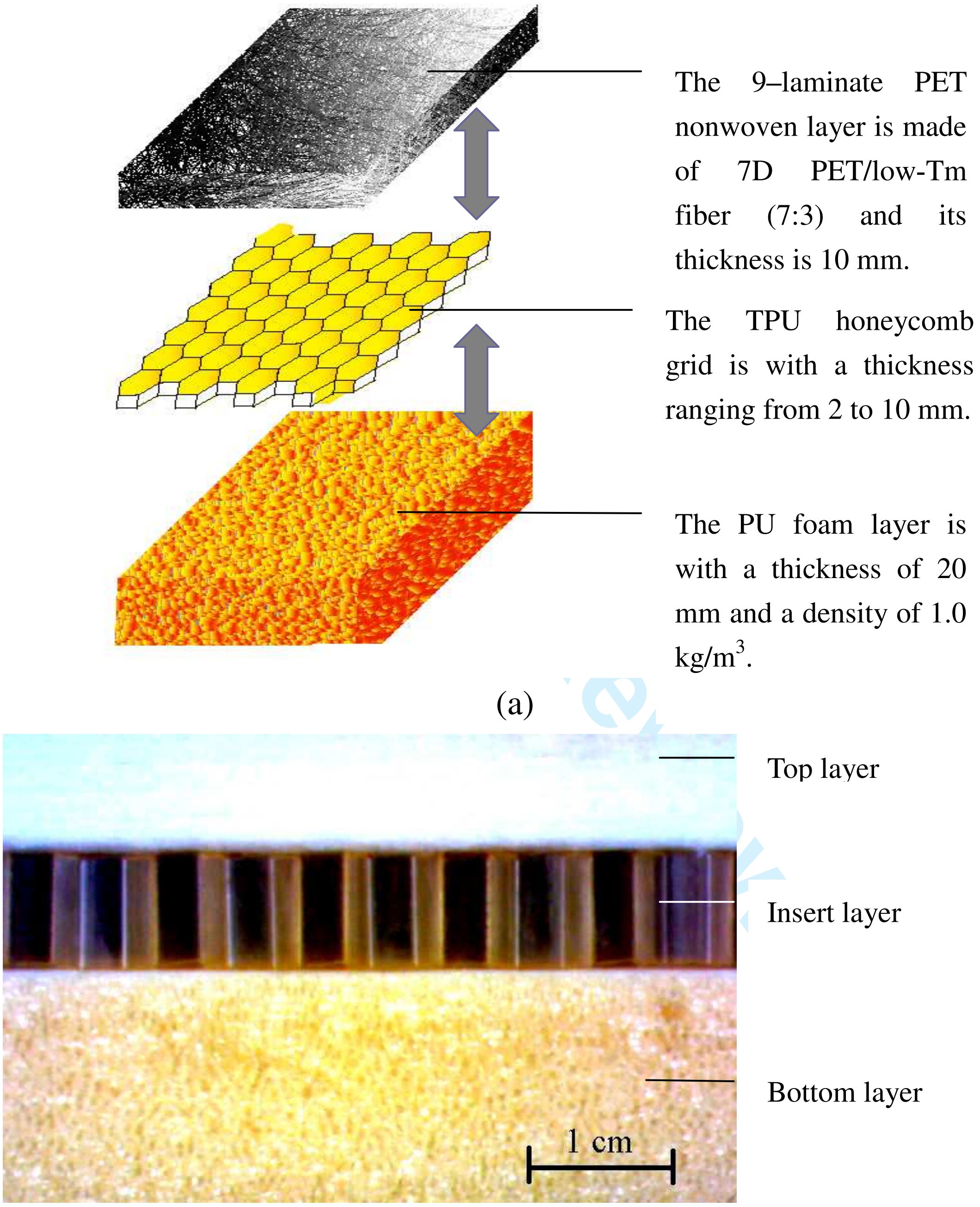


Figure 7 The sound absorption coefficient of the PET/TPU/PU sandwich plank. The top layer is the PET nonwoven layer made from 7D PET and low-Tm fiber (7:3). The bottom layer is the PU foam layer with a thickness of 20mm and a density of 1.0 kg/m$^3$. The thickness of the TPU honeycomb grid (insert layer) varies from 2 to 10mm in order to determine its influence on the sound absorption coefficient.




(b)

Figure 8 (a) is the cubic cross-section of the PET/TPU/PU sandwich plank and (b) is the illustration of the PET/TPU/PU sandwich plank taken by an optical microscope. The top layer is the 9-laminate PET nonwoven layer which is made of 7D

PET/low-Tm fiber (7:3) and then compressed in a thickness of 10mm. The insert layer is TPU honeycomb grid with a thickness ranging from 2 to 10mm. And the bottom layer is the PU foam layer which is with a thickness of 20mm and a density of 1.0 kg/m$^3$.

## The PU Foam Layer

### *The optimum thickness of the PU foam*

The PET/TPU/PU sandwich plank was fabricated according to the following parameters: the top layer was 9-laminate PET nonwoven layer with a thickness of 10 mm; the insert layer was TPU honeycomb grid with a thickness of 10 mm; and the bottom layer was PU foam with a density of 1.0 kg/m$^3$. The PU foam was formulated with foam reagent A and hardener reagent B blended in the volume ratio 1:1. Figures 9 and 10 show the sound absorption coefficient when the thickness of the PU foam layer varied from 10 to 30 mm. The PU foam layer had closed pore and the resonance over its surface helped prevent the sound energy from penetrating. However, PU foam layer with a thickness of 10 mm was not thick enough for low frequencies; meanwhile, some sound waves still penetrated the sound absorption materials and were reflected by the rigid wall so the sound absorption ability was not good. With a thickness of 20 mm or of 30 mm, the PU foam layer was good enough to prevent the sound energy from penetrating and thus engendered vibration for sound absorption. Hence, the optimum thickness of the PU foam was determined as 20 mm and the sound absorption coefficient was between 0.89 and 0.95 on the frequencies from 2000 to 4000 Hz.

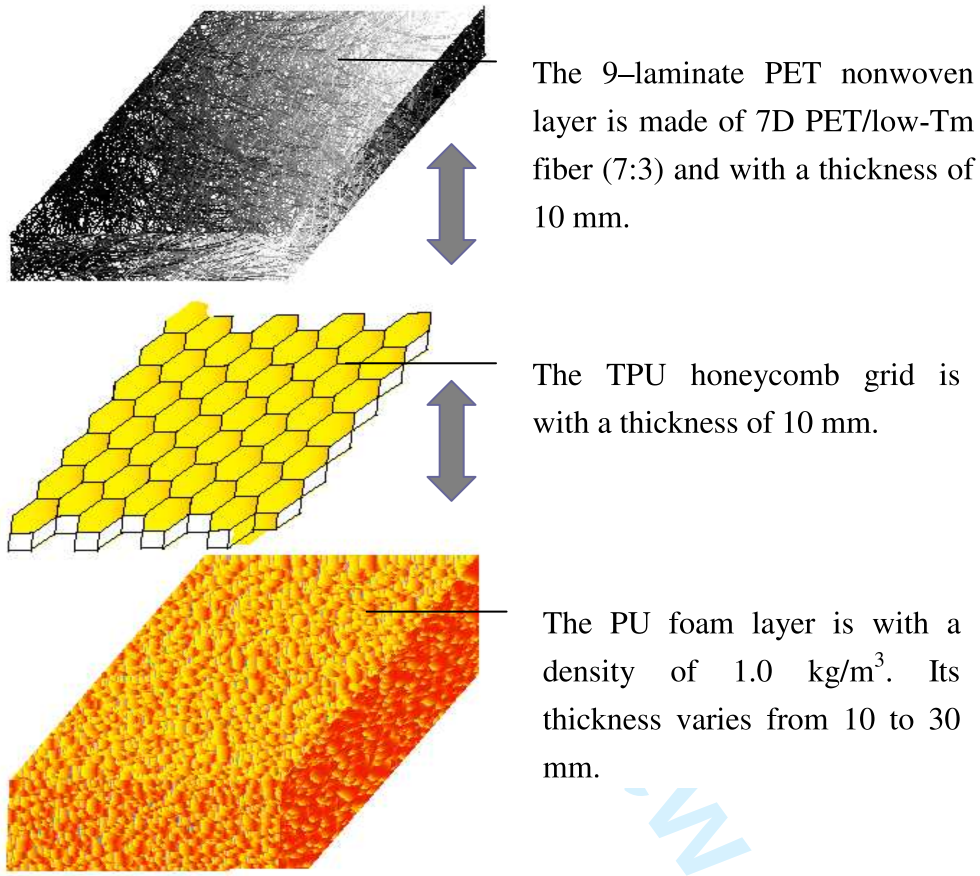



Figure 9 The cubic cross-section of the PET/TPU/PU sandwich plank. The top layer is the 9-laminate PET nonwoven layer which is made of 7D PET and low-Tm fiber (7:3) and further compressed in a thickness of 10mm. The insert layer is the TPU honeycomb grid with a thickness of 10mm. The bottom layer is the PU foam layer which is with a thickness varying from 10 to 30 mm and a density of 1.0 kg/m$^3$.

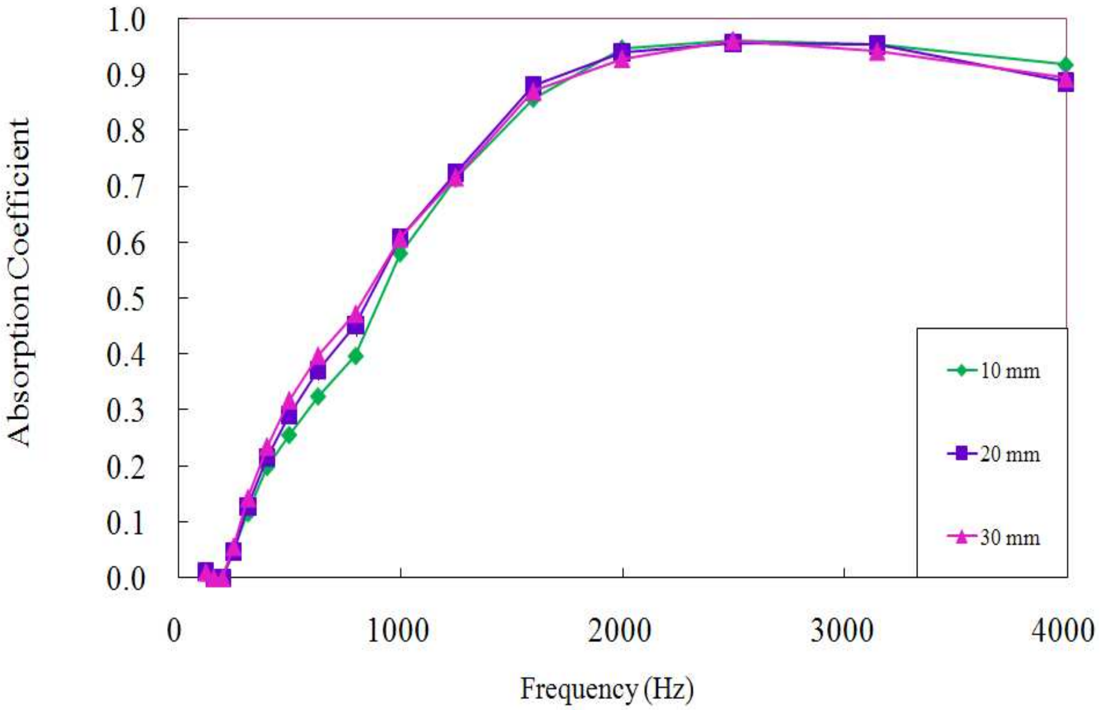



Figure 10 The sandwich plank is composed of PET/TPU/PU layers. The PET nonwoven layer, top layer, is made from 7D PET and low-Tm fiber (7:3). The TPU honeycomb grid, insert layer, is with a thickness of 10 mm. And the PU foam layer, bottom layer, is with a density of 1.0 $kg/m^3$; furthermore, the thickness of the PU foam is altered from 10 to 30 mm in order to determine its influence on the sound absorption coefficient.

*The optimum density of the PU foam*

The sandwich composite plank was consisted of 1) PET nonwoven sheet comprising 9 laminates and with a thickness of 10 mm, 2) the TPU honeycomb grid with a thickness of 10mm and 3) the PU foam which was formed by blending foam reagent A and hardener reagent B (blended) in the volume ratio 1:1 and with a thickness of 20 mm. The density of the PU foam was changed from 0.5, 1.0, 1.5, 2.0, and 2.5 $kg/m^3$ in order to see its influence on the sound absorption coefficient as shown in Figure

11 and 12.

When the PU foam reached a certain density, its sound absorption performance became better. In particular, its foam structure was complete to insulate the sound waves when the density of the PU foam sheet was 1.0 $kg/m^3$. However, when PU foam layer was with a density of 0.5 $kg/m^3$, its structure was not even comparatively. During the process of foaming, the stress PU foam layer took was lower, thus there were uneven pore diameters. When sound waves transformed into mechanical energy and were transmitted into the PET/TPU/PU sandwich plank, the PU foam layer with uneven pore diameters failed in dispersing the vibration energy thus the average sound absorption coefficient was lower. Figure 13 shows the PU foam layer contains different pore diameters and a closed porous structure. Therefore, 1.0 $kg/m^3$ was the optimum density of PU foam layer and the sound absorption efficient was between 0.91 and 0.95 on the frequencies from 2000 to 4000 Hz.

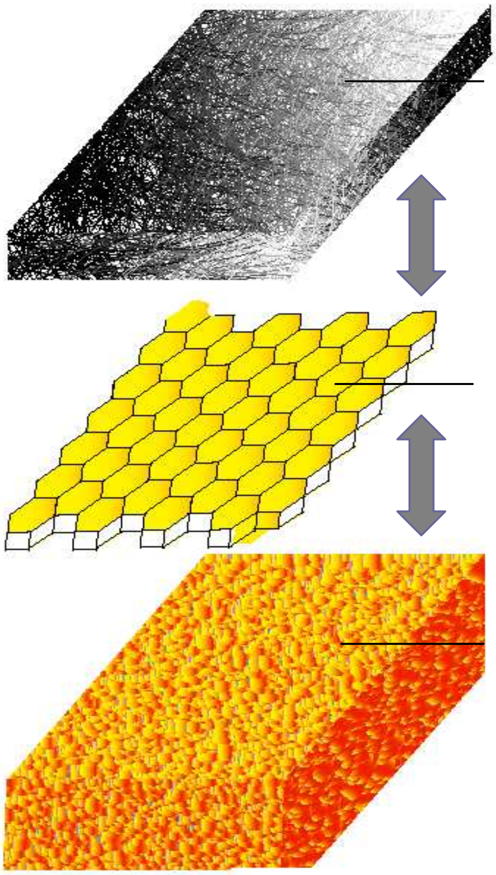



Figure 11 The cubic cross-section of the PET/TPU/PU sandwich plank. The top layer is the 9-laminate PET nonwoven layer which is made of 7D PET and low-Tm fiber (7:3) and then compressed in a thickness of 10mm. The insert layer is the TPU honeycomb grid with a thickness of 10mm. And the bottom layer is the PU foam layer which is with a thickness of 20 mm and its density varies from 0.5 to 2.5 kg/$m^3$.

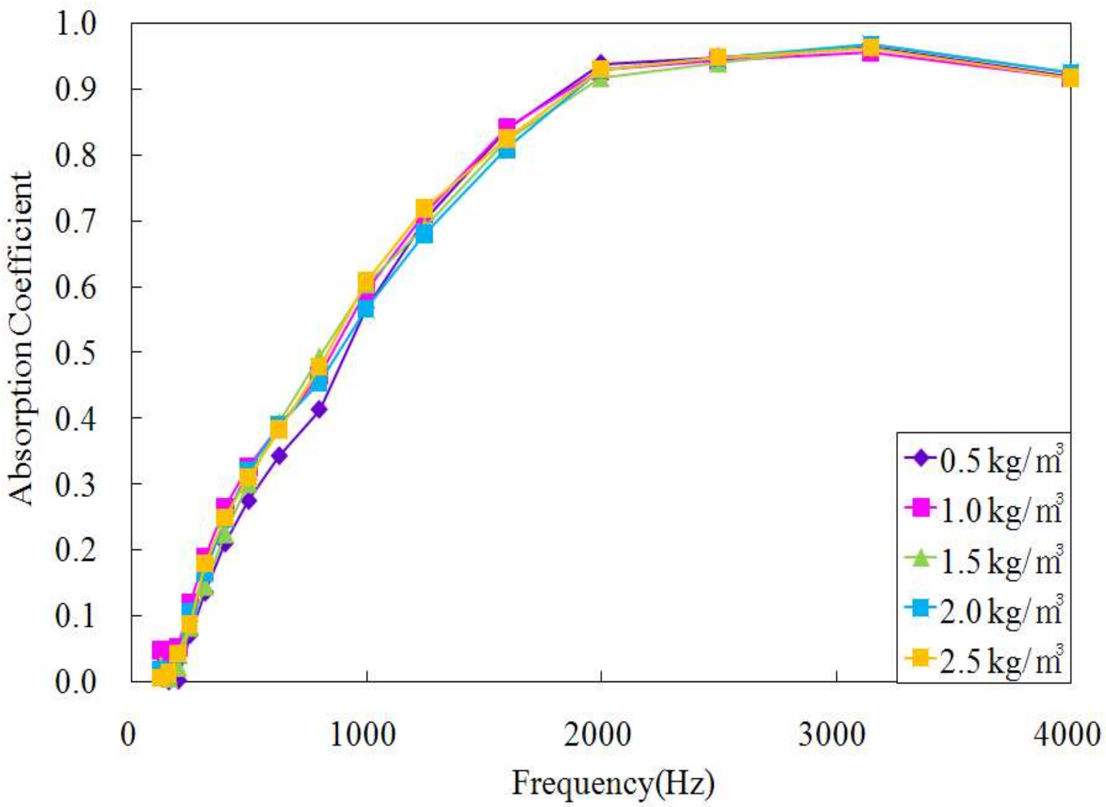



Figure 12 The sandwich plank is composed of PET/TPU/PU layers. The PET nonwoven sheet, top layer, is made from 7D PET and low-Tm fiber (7:3). The honeycomb grid, insert layer, is with a thickness of 10mm. And the PU foam sheet, bottom layer, is with a thickness of 20mm and various densities. The density of the PU foam is altered from 0.5 to 2.5 kg/m$^3$ in order to determine its influence on the sound absorption coefficient.

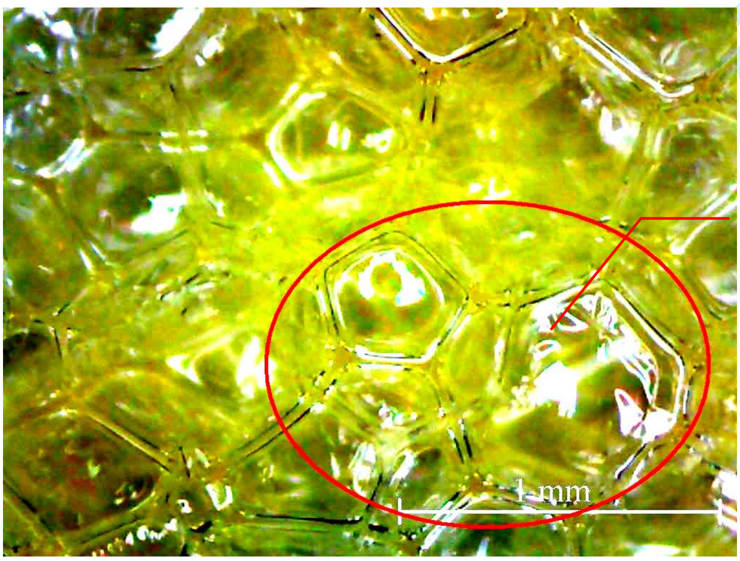



Figure 13 The illustration of the porous structure of the PU foam taken by optical microscope.

## CONCLUSIONS

According to the results of this experiment, a sandwich composite plank with high sound absorption coefficient in fibrous conformation was successfully manufactured. The PET/TPU/PU sandwich plank displayed the average sound absorption coefficient as 0.77 on the frequencies from 0 to 4000 Hz based on the following optimum parameters for three layers of the sandwich plank. For PET nonwoven layer, its optimum laminated counts, weight ratio (7D PET/ low-Tm fiber), and thickness were 9 layers, 7:3, and 10 mm. For TPU honeycomb grid, the optimum thickness was 10 mm. For the PU foam layer, its optimum thickness and density were 20 mm and 1.0 kg/m$^3$. In particular, the sound absorption coefficient of the PET/TPU/PU sandwich plank was 0.95 on the frequency of 3000 Hz.



## Acknowledgements

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## References

[1] H. C. Shih, C. Y. Chuang. Noise Control Manual, Noise Control Network. 1987.
[2] J. H. Lin, C. W. Lou, C. K. Lu, W. H. Hsing. Functional Fabric of Hybrid

Stainless steel/Polypropylene and the Electrical Properties of Thermoplastic Composites. Journal of Advanced Materials 2004; 1(36):63-68.

[3] J. H. LIN, C.W. LOU, C. K. LU, W. H. HSING. Processing of Thermoplastic Composites Produced by Polypropylene Nonwoven Selvage. Journal of Advanced Materials 2004; 1(36):57-62.

[4] Z. Z. Yang, J. H. Lin, I. S. Tsai, T. Y. Kuo. Combining Activated Carbon Fabric and Polypropylene Nonwoven Electret. Journal of Advanced Materials 2004; 2(36):3-9.

[5] Hsin-Chuan Chen, Kuei-Chi Lee, Jia-Horng Lin. Electromagnetic and Electrostatic Shielding Properties of Co-Weaving-Knitting Fabrics Reinforced Composites. Composites Part A: Applied Science and Manufacturing 2004; 11(35): 1249-56.

[6] C. W. Lou, J. H. Lin, K. H. Su. Recycling polyester and polypropylene nonwoven selvages to produce functional sound absorption composites. Textile Research Journal 2005; 5(75):390-94.

[7] C. W. Lin CW, J. H. Lin. Manufacture and application of high-performance geogrids with PP/PET composite covered yarn. Textile Research Journal 2005; 6(75): 453-57.

[8] J. H. Lin, C. H. Lei, C. H. Chang, K. M. Sun. Electrical Conductive Composites Produced by Laminated Nonwovens via Thermal Compression. Journal of Advanced Materials 2005; 4(37):32-35.

[9] Jia-Horng Lin. The Effect of Acid and Alkali Treatment on the Mechanical Properties of High Performance PP/PET Composite Geogrids. Journal of Advanced Materials 2006; 4(38): 63-67.

[10] H. C. Chen, K.C. Lee, J.H. Lin & M. Koch. Fabrication of conductive woven fabric and analysis of electromagnetic shielding via measurement and empirical equation. Journal of Materials Processing Technology 2007; (1-3) 184: 124-30.

[11] J. H. Lin, C. W. Lou, J. M. Chen, C. T. Hsieh & Z. H. Liu. PET/PP Blend with Bamboo Charcoal to Produce Functional Composites: Evaluation of Functionalities. Advanced Materials Research 2008; 55-57:433-36.

[12] T. Y. Huang, K. C. Chan. Study of nonwoven acoustic. Chinese Culture University of the 5th Department of Textile Engineering Thesis Album 1993; 365-70.

[13] D. B. Callaway and L. G. Ramer. The use of perforated facings in designing low frequency resonant absorbers. J. Acoustic. Soc. Am. 1952; 24:309-12.

[14] K. Attenborough. Acoustical characteristics of rigid fibrous absorbents and granular material. Journal of the Acoustic Society of America 1983; 73(3):785-99.

[15] Olek, J., W.J. Weiss & N. Neithalath. Concrete Mixtures That Incorporate Inclusions to Reduce the Sound Generated in Portland Cement Concrete Pavement. Final Report 2004; SQDH2004-2.

[16] C. Y. Chu, P. H. Lin, C. H. Lo. Vibration Cover Acoustic Impedance of Porous Sound Absorption Material. Republic of China Vibration and Noise Association of Engineering Thesis Album 2008; 394-496.

[17] ASTM E 1050 – 07. Standard Test Method for Impedance and Absorption of Acoustical Materials Using A Tube, Two Microphones and A Digital Frequency Analysis System. Revised 2007.