Sound absorption behavior of combined woven fabrics and nonwoven fabrics

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Abstract

It has been known that woven fabrics and nonwoven fabrics exhibit absorption capability. Despite this, both have different characteristics in absorption. The absorption of woven fabrics occurs due to resonance system which has a narrow absorption bandwidth but it is tunable for low frequency absorption. Meanwhile, that of nonwoven fabrics is present due to mainly visco-thermal effect of porous media so that the wide absorption bandwidth can be obtained at mid-high frequency. This works is focused to investigate the possibility to combine features of each fabrics in order to have a better performance of textile-based absorber. Experimental works on some configurations of combined woven fabrics and non-woven fabrics are conducted. It is found that some absorption enhancements are observed compared to original performance of each material. Hence, both materials are complementary to produce a better performance in overall. However, such a combination should be realized with a great care as absorption performance at mid-high frequency can be deteriorated or lead to poor results.

Keywords: woven fabric, non-woven fabric, sound absorption, textile based absorber

1. Introduction

Woven fabrics backed up with an air cavity can be considered as micro-perforated panel (MPP) absorber. A viscos-inertial effect that exists in the micro-perforation of woven fabric is useful to obtain absorption capability [1, 2] while Maa models [3, 4] are applicable to predict sound absorption of such an absorber system. To overcome a relatively narrow absorption bandwidth of MPP, Maa recommends to create minute holes between 0.1-0.3 mm to obtain broadband absorption up to 3-4 octaves [4]. Otherwise, the use of multi-layer can satisfy such a purpose as demonstrated by Prasetyo et al. [5]. Apart from this, a proper of resistivity and a suitable cavity depth can enable MPPs to absorb sound energy at low frequency. Nonwoven fabrics are made of textile fibers bonded together by chemical, mechanical and heat
treatment. Hence, resulting porosity of such material are formed by the fibers. Like other fibrous porous material, the non-woven fabrics are attractive due to their absorption performance at mid-high frequency where visco-thermal effects take place to determine associated absorption characteristics [6]. Numerous studies on nonwoven fabrics have been conducted as found in Refs. [7, 8]. Meanwhile, combination of nonwoven fabric and other material like tricot knitted fabric, double weave fabric, polyethylene membrane and paper can be found in [9-11]. Recently, applying woven fabric on top of non-woven layer have been investigated [12, 13]. All studies indicate that nonwoven fabric absorption performance is good and pronounced at mid-high frequencies, and the use of multi-layer woven fabrics and non-woven fabrics are useful to get better performance. In this work, combinations of woven fabrics and non-woven fabrics into a single absorber system is considered. For this, five woven fabrics with different micro size perforation are employed and combined with a nonwoven fabric made of recycled fabric. It differs from [12, 13], air-cavity layer is also considered in the combination. The proposed absorber system is then evaluated by observing absorption characteristics particularly absorption bandwidth and maximum absorption coefficients. The influence of perforation ratio of woven fabrics to overall performance is also discussed.

2. Material and Methods
2.1 Fabric material
Woven fabric consists of warp yarns and weft yarns. The first yarn is weft yarn in x-direction and warp yarn in y-direction (vertical). The density of woven fabric consists of the number of warp and weft yarns in inch. There were 5 fabrics from different the weft density. The warp density for all woven fabrics are 40 yarns/cm. The weft density were varied from 18, 22, 26, 30 and 32 yarns/cm. In this study, TR Ne120 was used for weft and warp yarns. The TR yarn is a blended yarn consisting of polyester (65%) fiber and Rayon (35%). The structures of woven fabric are 2/2 weft rib, as shown in figure 1. Structure of 2/2 weft rib is formed by two types of yarn. The warp yarns float over two weft yarns and then interlace to the third and fourth weft yarns. These yarns interlace and float each other creating holes. Therefore, the resulting size and the form of holes in woven fabrics can be adjusted by a weaving machine. The size of hole diameter is varied between 0.059 mm and 0.144 mm as can be seen in table 1.

![Figure 1. Structure of woven fabrics and geometrical hole parameters](image)
Considering hole definition of fabrics in figure 1, the hole diameter \( d \) of woven fabrics is defined as follows.

\[
d = 2 \sqrt{\frac{BC}{\pi}}
\]  

The perforation ration \( \sigma \) of woven fabrics are defined as follows.

\[
\sigma = \frac{BC \times 2.100\%}{DE}
\]

| Fabric | Weft density (yarns/cm) | Hole diameter (mm) | Perforation Ratio (%) |
|--------|-------------------------|--------------------|-----------------------|
| W1     | 18                      | 0.144              | 9.37                  |
| W2     | 22                      | 0.121              | 5.04                  |
| W3     | 26                      | 0.109              | 3.88                  |
| W4     | 30                      | 0.064              | 2.84                  |
| W5     | 32                      | 0.059              | 2.04                  |

The samples of nonwoven fabric is made of recycled fiber with the low melt fiber that it is consolidated by heat. The thickness of nonwoven fabric is nominally 10 mm, the gram per square meter (GSM) is 1000 g/m² and the size of diameter fiber is 26 mm.

### 2.2 Methods

The geometrical properties of woven fabric and nonwoven fabric were characterized using a digital microscope. Figure 2 shows surface morphology of 5 woven fabrics designated as W1, W2, W3, W4 and W5 respectively while nonwoven fabric as NW.

![Figure 2. Samples of woven fabric (W1-W5) with the difference of hole diameter and Non-woven fabric (NW) considered in experimental works.](image-url)
As shown in figure 3, the absorber system was realized by placing woven fabric in front of nonwoven fabric and the samples are designated as S1, S2, S3, S4 and S5 respectively. For sample S1-S5a, 15 mm air cavity depth $D$ was introduced between both materials while an impervious layer was presumably present as a backing layer. Meanwhile, sample S5b was considered where the air cavity depth $D$ was absence between both materials.

![Diagram of the absorber system](image)

**Figure 3.** The basic structure of absorber system in this study

Absorption coefficients of each sample were evaluated using impedance tube to ISO 10534-2 [14]. Figure 4 shows the schematic diagram absorption coefficient measurement and other relevant acoustic parameters by an impedance tube where the air cavity was set to 15 mm between woven fabric and nonwoven samples. A special holder was designed to hold the woven fabric as rigid as possible along its perimeter. To cover measurement frequency of 63 Hz – 6300 Hz, small and large tubes with a diameter of 30 mm and 100 mm respectively were employed.

![Diagram of the measurement setup](image)

**Figure 4.** The schematic of measurement setup: (a) impedance tube (b) holder and woven sample
3. Results and Discussions

3.1 Absorption Characteristics

Figure 5 present sound absorption comparison between each woven fabric and nonwoven fabric. It can be seen that sound absorption coefficients of woven vary depending perforation parameter as indicated in table 1 where peak frequency shift toward lower frequency and the absorption bandwidth as hole diameter and perforation ratio reduces (see table 2). Compared to that of nonwoven fabrics, absorption coefficients of woven fabrics are lower for higher perforation ratio (see figure 5 (a)) but the situation is opposite for lower perforation ratio where coefficient absorptions of woven fabrics are higher particularly for frequency below 4 kHz (see figure (b)-(e)). Apart from this, non-woven fabric absorption is outperformed at high frequency (>4500 Hz).

![Figure 5](image)

Figure 5. Sound absorption comparisons between woven fabrics and Nonwoven (NW): (a) W1 and NW; (b) W2 and NW; (c) W3 and NW; (d) W4 and NW; (e) W5 and NW
3.2 Influence of woven fabric perforation ratio and air cavity
Compared with original performance of woven fabrics, introduction of nonwoven fabric substantially improve the performance particularly extending the absorption to lower frequency as well as increasing the absorption coefficient as indicated by figure 6 (a)-(e). It is evident that additional absorption bandwidth of 300 Hz up to 1930 Hz can be obtained as shown in figure 6. Peak of sound absorption coefficient woven fabric W1 increase from 0.71 to 0.97 (S1) while W5 increase from 0.95 to 0.97 (S5). Half-absorption bandwidth W1 increase from 2950 Hz to 4880 Hz (S1) and W5 from 5550 to 5800 Hz (S5). Hence, the proposed approach is useful particularly to enhance performance of higher hole diameter or perforation ratio woven fabrics.

![Sound absorption comparisons between combined woven-nonwoven and woven fabric](image)

Figure 6. Sound absorption comparisons between combined woven-nonwoven and woven fabric: (a) S1 and W1; (b) S2 and W2; (c) S3 and W3; (d) S4 and W4; (e) S5a and W5; (f) S5b and W5
Without air cavity between woven fabrics and nonwoven fabrics, the absorption performance can lead to poor result as shown in figure 6 (f). It is clear that peak absorption and half absorption are lower than the original performance of W5 as indicated by table 2 (see S5 (NW+W5)\textsuperscript{b}) where the peak of absorption is reduced by 0.11 and the half-absorption bandwidth is reduced by 320 Hz. It suggests that combination of woven fabrics and non-woven fabrics without air cavity can lead the resistance of total surface impedance to shift from 1.

A different perspective is also applicable where such a combination can improve performance of non-woven fabrics particularly to have a better performance at lower frequency. It is obvious that the non-woven fabric performance at frequency 2 kHz or lower increase from 0.5 to around 0.9 while half-absorption bandwidth can be extended to below 1 kHz while original bandwidth is only around 2 kHz.

Table 2. Sound absorption coefficients of Nonwoven-Woven (S1-S5), Nonwoven (NW) and Woven (W1-W5) fabrics

| Samples     | The peak of Sound Absorption Coefficient (\(\alpha_{\text{max}}\)) | Half-Absorption Bandwidth, \(\Delta\alpha_{0.5}\), Hz | Improvement the peak of Sound Absorption Coefficient (\(\alpha_{\text{max}}\)) | Improvement Half-Absorption Bandwidth, \(\Delta\alpha_{0.5}\), Hz |
|-------------|------------------------------------------------------------------|---------------------------------------------------|-------------------------------------------------|---------------------------------------------------|
| S1 (NW+W1)  | 0.97                                                             | 4880                                              | 0.26 (S1-W1)                                   | 1930 (S1-W1)                                     |
| S2 (NW+W2)  | 0.95                                                             | 5300                                              | 0.05 (S2-W2)                                   | 1420 (S2-W2)                                     |
| S3 (NW+W3)  | 0.99                                                             | 5450                                              | 0.02 (S3-W3)                                   | 800 (S3-W3)                                     |
| S4 (NW+W4)  | 0.99                                                             | 5740                                              | 0 (S4-W4)                                      | 690 (S4-W4)                                     |
| S5 (NW+W5)\textsuperscript{a} | 0.97                                                             | 5800                                              | 0.02 (S5\textsuperscript{a}-W5)               | 300 (S5\textsuperscript{a}-W5)                  |
| S5 (NW+W5)\textsuperscript{b} | 0.84                                                             | 5180                                              | -0.11 (S5\textsuperscript{b}-W5)              | -320 (S5\textsuperscript{b}-W5)                 |
| NW          | 0.93                                                             | 4300                                              |                                                 |                                                  |
| W1          | 0.71                                                             | 2950                                              |                                                 |                                                  |
| W2          | 0.90                                                             | 3880                                              |                                                 |                                                  |
| W3          | 0.97                                                             | 4650                                              |                                                 |                                                  |
| W4          | 0.99                                                             | 5050                                              |                                                 |                                                  |
| W5          | 0.95                                                             | 5500                                              |                                                 |                                                  |

\textsuperscript{a} with air cavity between woven and nonwoven fabric 15 mm

\textsuperscript{b} without air cavity between woven and nonwoven fabric

4. Conclusions
It is found that combination of woven fabric and nonwoven fabric are useful to increase the sound absorption coefficients and half-absorption bandwidth compared to original performance of each structure. Such a combination is more applicable to enhance performance of greater hole diameter or perforation ratio woven fabrics where the performance is typically poor. On the way other around, adding woven fabrics on top of nonwoven fabrics can help the performance of nonwoven fabrics in extending bandwidth and absorption coefficient at low frequency. Meanwhile, the presence of air cavity between woven fabrics and nonwoven fabric is important to maintain resistance of total surface impedance around its optimal value. Hence, poor results of such a combination can be avoided.

Acknowledgements
This work was funded by Basic Research Program of DIKTI/BRIN 2020. The first author is also grateful to Politeknik STTT Bandung for providing the machine to fabricate the measurement samples.
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