Sound absorption enhancement of nonwoven felt by using coupled membrane – sonic crystal inclusion

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Abstract. The experimental results from laboratory test on the sound absorption performance of nonwoven felt with an array thin tubes and sonic crystal inclusions reported in this paper. The nonwoven felt sample was produced by a local company with 15 mm in its thickness and 900 gsm. The 6.4 mm diameter plastic straw was used to construct the thin tubes array while the sonic crystal is arranged in a 4 x 4 lattice crystal formation. It made from a PVC cylinder with 17 mm and 50 mm in diameter and length respectively. All cylinders have two holes positioned on 10 mm and 25 mm from the base. The results show that both treatments, array of thin tube and sonic crystal inclusions are effectively increased the sound absorption coefficient of the nonwoven felt significantly especially in the low frequency range starting from 200Hz.

1. Introduction

The patch from textile industries has a potential economic value. Since it made from yarn through an industrial machining process, it can be recycled to produce fibrous sound absorber for various applications including automotive, shipping and building acoustics [1]. Nonwoven felt is a common material that widely uses as a sound absorber in automotive industries such as for doors, roofing, flooring, hood and much more. It made from the mix of the textile patch with a certain commercial binder which is melting on 110°C-200°C [2].

Despite the fibrous structure brings a very good performance on noise reduction for the high frequency band, it needs a more advanced approach to making the nonwoven felt perform the better absorption at the mid and low frequency range. The various approach has been developed by previous researchers accordingly. For example, the inclusion of permeable and perforated membrane have reported by Sakagami et al (2014) and Harjana and Yahya (2015) respectively. It found that the membrane structure affect to the reactance of the cavity backed perforated absorber and produces significant increment to the sound absorption performance on the mid to high frequency range above 500 Hz [3,4].

Another approach by using short thin constrained tube has been reported by Yahya and Harjana (2013) and followed by the compartmented cavities approach by Li et al (2015, 2016). This cavity resonance approaches successfully shifting the sound absorption performance to 200 Hz but it has industrial constraint due to the geometrical design which is impractical for mass production [5-7]. The most attractive approach among researchers recently is sonic crystal assisted sound absorber which is...
featuring possibility for tuning the local Helmholtz resonant to reduce the noise on certain intended
frequency band [8-11]. In this paper, a combined permeable membrane, thin tubes array, and sonic
crystal inclusion approach are reported. The proposed combining of three different noise reduction
techniques in a single integrated inclusion design is expected to produce a much better sound absorber
concept which is less constraint in the industrial perspective.

2. Methods

The transfer function based two microphones technique refer to ASTM E1050 was conducted to
measure the sound absorption coefficient of the test sample. Since this work is focused on the low
frequency band up to 1.6 kHz, the large tube of B&K 4206 was utilized in the laboratory test. The
membrane layer was produced by hand laying up the technique of a commercial leak-proof product on
the surface of the nonwoven felt. The layering steps have been repeated for three times followed by an
open air drying process. The nonwoven felt has 15 mm in thickness and 900 gsm produced by a local
manufacturer while the thin tubes and sonic crystal elements are made from plastic straw and PVC
tube of 6.4 mm and 17 mm in diameters respectively. The sonic crystal element has a single
geometrical size 50 mm in the height with a 2 mm hole on the wall. It varying in two different
positions of 10 mm and 25 mm from the bottom end as illustrated in Figure (1).

Figure 1 The test samples: (a). Nonwoven felt, (b). Array of thin tubes, (c). The sonic crystal model

The laboratory setup is presented in Figure (2). B&K 3160-A LAN-Xi type was used in connected
with the power amplifier B&K 2716C and impedance tube B&K 4206. Random noise is generated
from the loudspeaker and the incident and reflected waves are decomposed from the captured signals
by a pair of quarter-inch microphone B&K 4187.

Figure 2 laboratory setup for sound absorption measurement.

There is three frequency response are being calculated in the decomposition process: frequency
response $H_1$, frequency response associated with incident waves $H_i$, and the frequency response
function associated with the reflected wave $H_r$.

The reflection coefficient is given by,
\[ R = \left( \frac{H_2 - H_1}{H_r - H_1} \right) e^{j2k(l+s)} \] (1)

where \( k \) is the wave number, \( l \) is the distance of the first microphone to the sample surface, and \( s \) is the spacing between microphones. The normalized impedance ratio and sound absorption coefficient can be calculated by using the following equation,

\[ \frac{z}{\rho c} = \frac{1+R}{1-R} \] (2)

\[ \alpha = 1 - |R|^2 \] (3)

3. Results and Discussion

Figure (3) shows that the nonwoven felt does not perform as an effective sound absorber for the low frequency range. It happened since the sound waves passing through the material without energy dissipation. The viscous damping did not occur due to the wavelength are much longer compared to the sample dimension. As the surface of the nonwoven felt covered by the leak-proof silicon layer, the sound absorption coefficient increased significantly. It happened for all frequency starting from 400 HZ and reach the maximum value of 0.75 in the frequency range between 700 Hz to 1.2 kHz.

This phenomenon is in between of the similar results as previously reported by Sakagami et al [3] and Harjana and Yahya [4]. It means that silicon layer brings multiple impacts to the nonwoven felt properties. It does not only affect the surface impedance value but the more significant it is produced membrane type resonance on the surface of the nonwoven felt. As the membrane oscillates on its resonant modes, the fibrous structure of the nonwoven felt below the membrane are also oscillate in the same mode accordingly. It then increases fibrous damping by the nonwoven fibers and porosity and resulting the much higher sound absorption coefficient.

![Figure 3](image-url)

**Figure 3** Impact of silicon layering on the sound absorption coefficient of nonwoven felt.

Another result presented in Figure (4). The sound absorption coefficient are slightly increased at two different frequency range. The first one in 500 Hz to 800 Hz which is associated with coupling effect of the thin tubes array with the surrounding cavity. The second increment on the high frequency band around 1.4 kHz and 1.6 kHz are related to the resonant mode of the half wavelength resonators of the thin tubes array.
It is clear from Figure (4) that coupling effect of the thin tubes array which is half wavelength resonators with the surrounding cavity including the membrane layer on the surface of nonwoven felt tends to shift the response. The resonance absorption occurs simultaneously due to the cavity, the thin tubes array, and the membrane. It changes the reactance of the coupled structure and shifting the response to the lower frequency. In the same time, the fibrous and porous layer of nonwoven felt also oscillated and increased the sound energy dissipation into heat. It brings a better understanding of the possibility of manipulating the resonance absorption and coupling effect as the new approach for increasing the sound absorption coefficient of the nonwoven felt.

This new approach was then implemented to create the another test model with the consideration of using the sonic crystal element instead of thin tubes array. It based on a fundamental reason related to the local Helmholtz resonant of the sonic crystal. In addition, it also considering to the scattering and multiple internal reflections which are both not occurred with the thin tubes array.

The result is presented in Figure (5). The proposed approach with coupled of membrane layer with the sonic crystal inclusion has a very promising performance. The sound absorption coefficient increases
at the all frequency range with the smallest absorption coefficient of 0.24 for the frequency of 200 Hz. This result is much higher compared to the initial nonwoven felt which is less than 0.05 for the same frequency. It also clear from Figure (5) that the sound absorption coefficient increase rapidly from 0.24 on 200 Hz to 0.9 on 500 Hz and then featuring flat response on the rest of the frequency range above it.

This evidence emphasizes and concludes that the sound waves energy are effectively dissipated by coupling of the membrane layer, the local resonant, and also by fibrous and porous nonwoven felt. In term of industrial application possibility, it is clear that since the proposed approach consists of a single geometrical dimension sonic crystal element, it much easier to mass production compared to the compartmented cavities and other techniques as proposed by previous researchers.

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