Laboratory investigation on the role of tubular shaped micro resonators phononic crystal insertion on the absorption coefficient of profiled sound absorber

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Abstract. This paper emphasizes the influence of tubular shaped microresonators phononic crystal insertion on the sound absorption coefficient of profiled sound absorber. A simple cubic and two different bodies centered cubic phononic crystal lattice model were analyzed in a laboratory test procedure. The experiment was conducted by using transfer function based two microphone impedance tube method refer to ASTM E-1050-98. The results show that sound absorption coefficient increase significantly at the mid and high-frequency band (600 – 700 Hz) and (1 – 1.6 kHz) when tubular shaped microresonator phononic crystal inserted into the tested sound absorber element. The increment phenomena related to multi-resonance effect that occurs when sound waves propagate through the phononic crystal lattice model that produce multiple reflections and scattering in mid and high-frequency band which increases the sound absorption coefficient accordingly.

1. Introduction
Surface modification techniques were commonly used for improving the performance of sound absorbers and sound diffusers. In regards to this purposes, the use of micro-perforated panel (MPP) occurs mostly in many reports and publications. The idea of MPP was initially provided by Maa in 1975 and has been a growing interest among researchers due to its ability on absorbing sound energy in a large frequency band [1,2]. Later many different approach and technique were proposed by other researchers to fulfill engineering requirement, especially in low-frequency range.

The use of multi-layer MPP with air banks between the layers [3], flexible membrane insertion [4], cavity, backed MPP by using Helmholtz resonators and compartmented cavities [5,6] and MPP with extended tubes was applied in various sound absorber design. That mentioned approach gave some advantages not only on shifting the absorption to the lower band but increase MPP performance at the mid and high-frequency range as well. The use of multi-layer MPP with different perforation ratio in its layers, for example, increase the total oscillating mass when sound waves are passing through perforations. It converts the sound waves energy into heat and the same time coupled cavity resonance effect due to the air banks occurs. The slightly different phenomena existed with the cavity backed MPP and extended tubes design where the absorption are related to the changes of resonator cavity and the length of extended tubes respectively. Coupled cavity resonance and extended viscous damping occur on the insertion of the flexible perforated membrane. When the membrane oscillates on its resonant modes, sound wave energy dissipated through viscous damping in a more effective way due to the increase amplitudes of the resonant modes. In the same time, the flexible membrane also...
works as an additional spring to the resonator cavity. It changes the reactance and produce higher absorption in the mid frequency range.

Later a new special low-frequency absorption technique has been growing rapidly in this decade. Resonant properties a new kind of artificial material known as phononic crystals or locally resonant sonic materials was reported recently including multilayer split tube and Helmholtz resonator based structure [7-9]. Researchers found that in such artificial crystal lattice exist some frequency ranges that classical waves were not transmitted. The Periodic arrangement of the crystal lattice and the properties of scatterers causing local resonance effect. Constructive or destructive interference occurs depending on the frequency of the waves [10]. It gives possibilities for fundamental functional and artificial acoustic materials design for shielding, filtering and guiding.

The insertion of tubular shaped microresonators and its impact on the absorption of profiled sound absorber reported in this paper. Two different profiled sound absorber model with two, five and seven wedge-shaped element on the top surface were investigated through laboratory experiments. The sound absorption performance test was conducted by using impedance tube technique refer to ASTM E1050 standard.

2. Experiment
Profiled surface cube-shaped sound absorber model used in the experiment presented in Figure 1. It made from 2 mm thickness hard paper with the dimension (50 x 50 x 50) mm in its long, wide and height respectively. There is two type of wedges shaped element were attached to the sound absorber, i.e., opened and closed element. Stacking of tubular shaped plastics microresonator with the dimension as presented in Table 1 was inserted vertically into the sound absorber model. The influence of horizontal micro-resonator lattice configuration, simple cubic (SC) and body centered cubic (BCC) also investigated.

![Figure 1. Three different cubes shaped sound absorber model used in the experiment.](image)

| Sample | Length (mm) | Diameter (mm) |
|--------|-------------|---------------|
| A      | 20          | 2             |
| B      | 20          | 3             |
| C      | 30          | 2             |
| D      | 30          | 3             |
| SC     | 50          | 5             |
| BCC    | 50          | 5             |
The laboratory test set up for sound absorption measurement by using B&K 4206 impedance tube technique illustrated in Figure 2. Random noise generated from an asignal generator inside B&K Pulse (4) and amplified (3). This amplified sound to be emitted from the loudspeaker (2) inside the tube while test sample (1) placed in the opposite position at the far end of the tube. The two microphones (5) captures both incidents and reflected waves to be analyzed through transfer function based spectral decomposition method. The absorption coefficient than was given by equation (1),

\[ \alpha = 1 - |R|^2 \]  

where \( R \) is the reflection coefficient of the test sample.

3. Result and Discussion

The influence of opened and closed profiled surface to the sound absorption coefficient presented in Figure 3.
The increasing number of profiled element gives a better results to the sound absorption of the sound absorber model. It is clear from Figure 3 the sound absorption increased with the number of profiled wedges. The better performance at higher frequency band for the opened attachment element (a) occurs since the top layer vibrates and oscillate the air resulting resonance and viscous damping effect at the tips of the opened element. Meanwhile, the closed element increased the cavity volume of the sound absorber (b) which takes into account on increasing the sound absorption in the low-frequency range.

Overall sound absorption increment occurs when the tubular shaped microresonators inclusion fitted inside the sound absorber model. One can see from Figure 4 that the inserted tubular shaped resonators with the various dimensions increase the sound absorption at the all frequency range both for the sound absorber model with five (a) and seven (b) profiled elements. The changes in impedance due to microresonator configuration and dimensions resulting multi-local resonance on each of the microresonator elements. According to Zao et al. [7], these local resonance occurs when the incident sound waves scattered from the opened profiled surface and then guided into propagation along the tubular shaped microresonators. Exponential energy losses then occur on this kind of guided waves since energy dissipation increase exponentially with the propagation distance.

**Figure 4.** Sound absorption due to microresonator insertion: five (a) and (b) seven element.

The lattice model also investigated in this research. One can see from Figure 5 the lattice structure simple cubic (SC) and body centered cubic (BCC) resulting multiple scattering which increases-the energy dissipation at higher frequency band. These multiple scattering occurs since the lattice normal
to the incident wave. But one knows that the incident waves propagates to the lattice structure as oblique incident waves since it is already scattered when wavefront hit the tips of profiled elements on the top of sound absorber model. This result gives the possibility for generating an additional local resonant modes due to the dimension of the microresonators or phononic crystal elements and the lattice constant. It means that functional artificial acoustic materials could be developed based on an array of tubular shaped microresonators to produce a new type of multi-local resonant material that fulfill specific engineering requirement. Further investigation and analysis need to conduct to get better understanding especially on the multiple scattering effect and transmission properties of the multi-local resonant material for application in the low-frequency range.

4. Conclusion
The profile sound absorber with tubular shaped micro resonator inclusion has a better sound absorption performance compared to the empty model without inclusion. Local resonance and multiple scattering occur on the opened profiled surface sound absorber models. The structure of tubular shaped microresonators works as an array of the wave guide that increase energy dissipation at multiple frequencies according to its length and dimensions. In addition, multiple scattering due to the lattice structure model increases energy loss in the high-frequency band. It gives possibilities for development of functional artificial local resonance based sound absorber which is different to the existing MPP based sound absorption techniques.

Acknowledgement
This research funded by Mandatory Research Grant, Research Institute (LPPM) of Sebelas Maret University, 2015.

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