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Investigation on the Composite of Pumice and Alumina Equipped by Quarter Wavelength and Helmholtz Resonators as Noise Absorber Material

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Abstract

Noise (unwanted sound) is a kind of pollution that hits public community in many cities and industrial areas, harms human health both physically and psychologically. The aim of the study is producing an acoustical composite as building material component for absorbing noise. The method was conducted by synthesizing and characterizing two kinds of samples: the first was made of crushed Pumice and Aluminium Oxide (Al_2O_3) by mechanical mixing with Polyvinyl Acetate (PVAc) as binder without resonator, and the second was equipped by Quarter Wavelength and Helmholtz Resonators. The Physical and Chemical Properties of each sample has been characterized by EDAC, FTIR, XRD, SEM, Universal Testing Machine and Impedance Tube. The experiment results show that the composite of pumice and Aluminum Oxyde with PVAc as binder has high strength, waterproof and fire resistant. It so happens the value of absorbtion coefficient (α) of produced composite without resonator below 0,12 at all measured frequency area. The similar composite that equipped by Quarter Wavelength Resonator has value about 0,28 at frequency range between 1000 Hz – 4500 Hz, while the composite that equipped by Helmholtz Resonator inside the synthesized composite has value about 0,9, it effectively absorbs noise especially at low frequency areas below 1000 Hz. It is concluded that the tested composite which equipped by resonator is a good alternative as a building material component for noise absorber at low and medium frequencies areas because low in cost and easy to produce.

Keywords: Noise, Health, Pumice, Al_2O_3, PVAc, Resonators.

Introduction

Noise is unwanted sound that often harms human health. It can cause hearing loss and interferes brain, eyes, and many kinds of human nervous system. Industrialization and development of many fields in a country have caused environmental pollution including noise and automatically increase the risk to human and environmental health[1]. Noise has significant impact on human health. WHO's definition of health includes total physical and mental well being and WHO working group stated: "Noise must be recognized asa major threat to human well being". According to WHO, health technologies are developed to solve health problem and improve the quality of lives[2]. In extremely noisy work environments, hearing protection that provides high levels of attenuation is necessary[3]. Many kinds of effort have been carried out by researchers to solve human problems. The natural fiber composites be used to reduce visibility in the infra red, visual, audio and radio frequency spectrum that takes into account the heat, sound and other emissions[4]. The ultrasonic sensor system is designed to combine two parts: voice alert part for blind persons which will send voice as in car sensors, and vibration part for deaf persons which as a rod vibrated when approached from obstacles[5]. In a study on acoustics, the results show that the sound speed in the ocean is an increasing function of temperature, salinity, pressure, and depth[6]. Then the observations on magneto-acoustic waves in coronal loops reveal that there is a lot of examples of small amplitude waves and oscillations in different coronal structures are mainly in the form of slow magneto-acoustic waves[7]. In building design, the result of using diffusive architectural surfaces reveal some of their effects on spatial perception[8]. Building structural has numerous degrees of freedom due to their connection[9]. There are many kinds of material can be used for noise absorber. Porous material often be used for noise abatement. However, none of these studies uses composite of pumice and aluminium oxide that equipped by resonators as building material component for reducing noise. The aim of the research is producing an acoustical composite by synthesizing powdered porous pumice and aluminium oxide which both were bound by polyvinyl acetate and equipped by combination of quarter wavelength resonator and Helmholtz resonator then characterizing the product to know its physical and chemical properties especially its ability in absorbing noise. Pumice is a generic term used to describe porous solids produced during the cooling of magma as a result of volcanic activation, the voids are as a result of the outflow of gases from the magma produces. Because of the gases small hollow voids renders the resulting solids to have a very porous structure, and this is why pumice has high porosity and absorption[10]. In the study on the effect of pumice rate on the gamma absorption parameters of concrete shows that increasing pumice rate decreases the value of attenuation coefficients. This could be strongly due to the increase in porosity and decrease in density of the concrete following the addition of pumice mineral[11]. For Alumina, it improves the properties and depresses the devitrification of soda-lime-silicate glasses. The infrared spectra measurements suggest that this case mainly attributed to the network strengthening effect of the added Al_2O_3[12]. Acoustic investigation shows that acoustic impedance for Al_2O_3 is 42,08 Mrayls, Stainless steel 45,24 Mrayls, and Air 0,0004 Mrayls[13]. The study on alumina trihydrate shows that the tensile modulus and hardness increased while elongation at break and tensile strength decreased with increasing ATH content[14]. For alumina foam, it exhibits excellent sound absorbing properties comparable with the best sound insulating polyurethane foams[15]. A binder is important factor for fabricating acoustical composite because the composition of binders (matrix) has a great influence upon the acoustical properties of the samples (absorption coefficient, impedance ratio, reflection coefficient)[16]. Poly Vinyl Acetate (PVAc) is an important polymer, the typical advantages of PVAc are flexibility, formability and low density[17]. Based on its properties, PVAc was used for binding powdered pumice and alumina. The Helmholtz resonator HR) is a simple acoustic system consisting of a rigid-walled cavity of volume *V*, filled with air and a neck of section *S* and the length *L* by which the cavity communicates (Figure-1). After a proper short exterior pressure excitation, the air filling the neck is starting to move back and forth damping out in time. The acoustic design by simulation and the optimization of more complex systems and acoustic materials based on HR are of great interest and under observation[18]. Helmholtz resonators reduce the noise level especially at the low frequency end of the sound spectrum, The amount of reduction can be increased by employing multiple resonators and ensconcing them can solve the problem of mounting HRs[19]. The concept of Helmholtz Resonator can be extended by coupling several Helmholtz Resonators which the resulting structure is called Helmholtz resonator tree [20]. A quarter-wavelength resonator is a tube like resonator with open and closed ends as shown in figure-1(b). In a quarter wavelength resonator, the one-third of tube length near the open inlet acts as a neck of Helmholtz resonator, and the two third of tube length acts as a cavity[21]. The absorption coefficient alpha (α) is a ratio of the absorbed and incident energy enables the following expression to be derived: $(\alpha) = 1 - |R|^2$, where $|R|$ is the magnitude of the pressure reflection coefficient. When predicting the absorption of porous absorbent, it is necessary to know the characteristic of the material in terms of the characteristic of impedance Z_c and complex wave number k_c. The characteristic of impedance Z_c is given by Delany-Bezley formula, equation (1) and (2):

$$Z_c = \rho_o.c_o\,(1+0{,}0571X^{-0{,}754}-j.0{,}087X^{-0{,}732}) \quad (1)$$
$$k_c = \omega/c_o\,(1+0{,}0978X^{-0{,}7} - j.0{,}087\,X^{-0{,}732})/c \quad (2)$$

where ρ_o dan c_o are the density and speed of sound in air and ω angular frequency. $X = \rho_o.f/\sigma$ where f is the frequency and σ the flow resistivity of the fibrous material. Zc dan kc are complex number. The imaginary part of Zc represents stored energy and the imaginary part of kc represents dampness in the medium. While Helmholtz resonators are in common use in applications such as acoustic elements in rooms and in duct silencers. The geometries of Helmholtz resonators are very diverse, but they all have two characteristic features in common: A *cavity* and a relatively small *opening* through which the sound energy enters the cavity as shown in figure-1(a) The energy of incident noise will be absorbed optimally by resonator when the resonant frequency (f_0) of the resonator caused by incident noise equals to the equation (3)

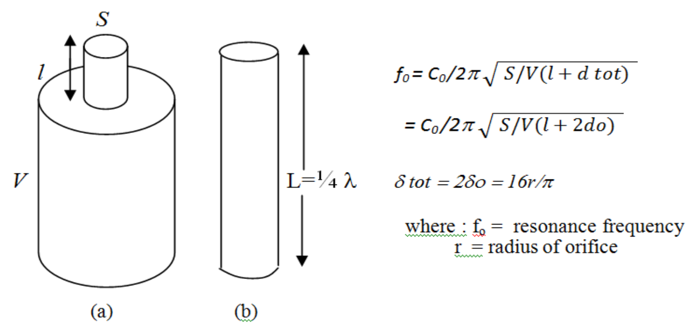


Figure-1
(a) A Helmholtz Resonator. The opening of the resonator is often referred to as the neck. The cavity volume *V*, the neck length *l*, the velocity of sound in air C_o, and the cross-section area *S* of the neck determine the resonance frequency of the resonator; (b) Quarter Wavelength Resonator.

A quarter-wavelength resonator is a tube like resonator with open and closed ends as shown in Figure-1(b). The measurement of the acoustic properties of acoustic samples was performed by impedance tube according to ASTM E1050-98 International Standard.

Material and Method

The procedure of the experiment basically started by synthesizing samples. For this study, 7 variations of samples were synthesized and tested. They are as shown in table 1. Every variation consists of 3 same samples. Among all the tested samples, the composite of pumice with Aluminium Oxyde (Al_2O_3) that binded by polyvinyl acetate (PVAc) (No.2 and No.4) are selected as the main samples because they are the strongest and lightest. No.2 is composite without resonator, and No.4 is composite equipped by resonator. The ratio in weight of selected composite, Pumice: Al_2O_3: PVAc is 1:1:1. Pumice and Al_2O_3 mixed and shattered by blender to form powder. The powder treated with polyvinyl acetate in order to bind the powder then molded to form samples. The diameter size of every sample is 3 cm and thickness 2 cm. After drying samples by red infra light, the samples tested by impedance tube apparatus for detecting their absorption coefficient. There are two variations of the tested samples: i. Three same samples without resonator. ii. Three same samples that each sample is equipped by Quarter Wavelength Resonator and Helmholtz Resonator.

Table-1
The composition of every sample prepared

No	Materials	Mass (gram)
1	Pumice Polyvinyl Acetate	60 30
2	Pumice Aluminium Oxyde Polyvinyl Acetate	30 30 30
3	Aluminium Oxyde Polyvinyl Acetate	60 30
4	Pumice Aluminium Oxyde Polyvinyl Acetate	30 30 30
5	Pumice Aluminium Oxyde White Cement	30 30 30
6	Pumice White Cement	60 30
7	Pumice Magnesium Sulfate White Cement	30 30 30

The instruments used in the experiment to test the samples. Absorption coefficient measurement (α) of every sample was performed according to ASTM E 1050-98 by using Impedance Tube 4206 T. The first measurement is for three same samples without resonator and the second measurement for three samples equipped by Quarter Wavelength Resonator and Helmholtz Resonator. The content of elements in the sample was detected by EDAC. Physical and chemical properties of the samples including composition, scale factor, and crystal system were performed by using Phillips Analytical X-Ray B.V. Diffractometer Type PW 1710 and FTIR Perkin Elmer Spectrum Version 10.03.02. BET-Quantachrome Nova was used for measuring surface area and pore volume of samples, and Universal Testing Machines Model 2000E Serial No. 010903 for measuring the strength of pressure. The morphology of the main sample was performed by SEM.

Results and Discussions

The result of the measurement of material composition by FTIR is shown in figure 3 and by XRD is shown in figure 4 and table 2. The tested samples and their SEM images are shown in figure 5{a) and 5(b), and the curves of acoustical properties measurement are performed in figure 6(a) and 6(b).

The spectrum of FTIR for composite fabricated by pumice, alumina and PVAc has some peaks of transmittance. The peak 1734,8 cm^{-1} indicates aldehyde C=O stretch. The compound type of peak 1311,5 cm^{-1} that at frequency range between 1340–1020 cm^{-1} indicates amines C-N, and the peak 1234,7cm^{-1} and 1011,2 cm^{-1} both indicate C-O bonding.

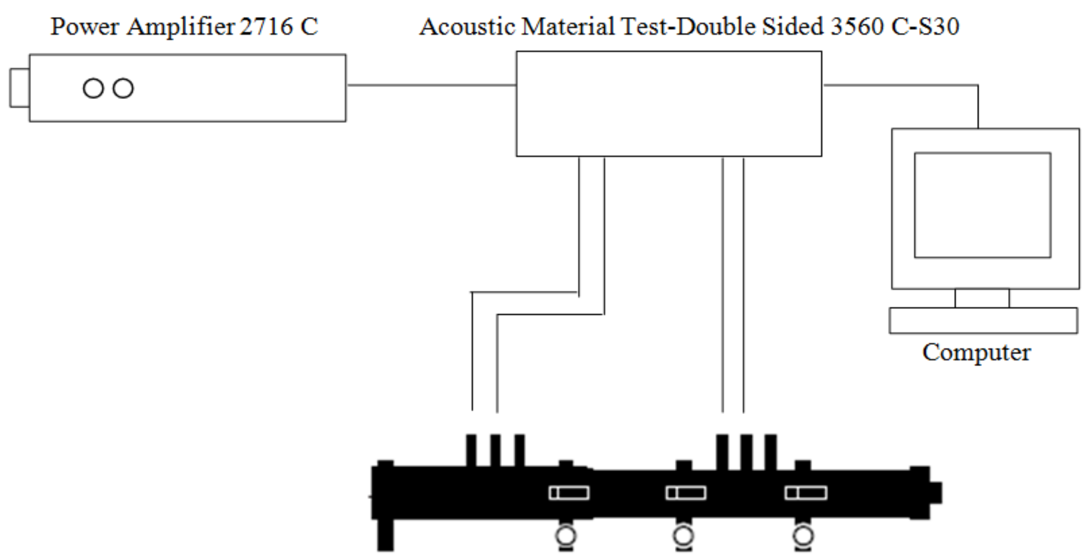


Figure-2
Schematic Representation of Typical Measuring Arrangement

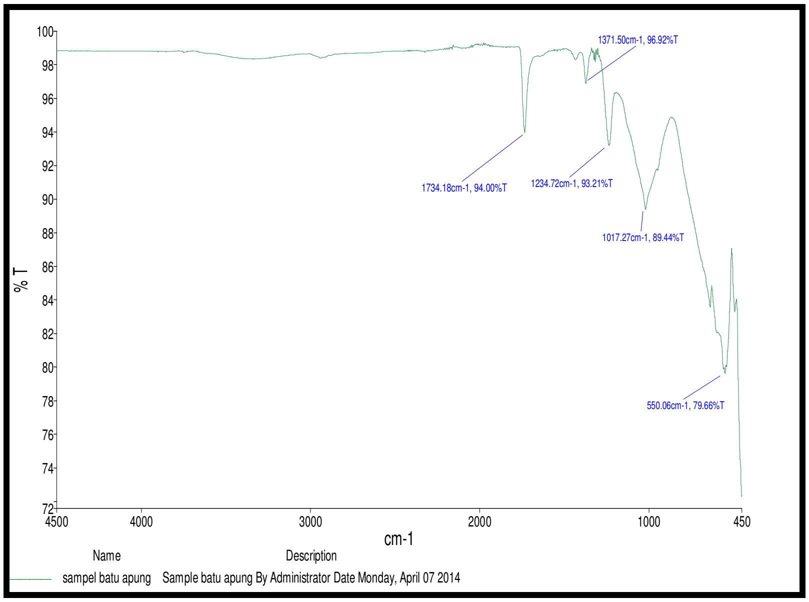


Figure-3
FTIR Spectrum of Composite Fabricated by Pumice, Alumina and PVAc

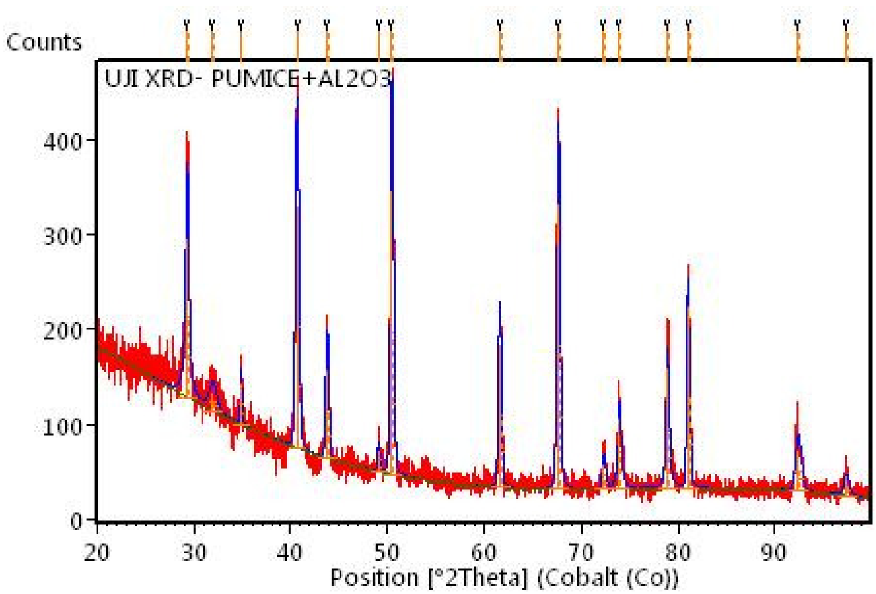


Figure-4
XRD Spectrum of Composite Fabricated by Pumice, Alumina and PVAc

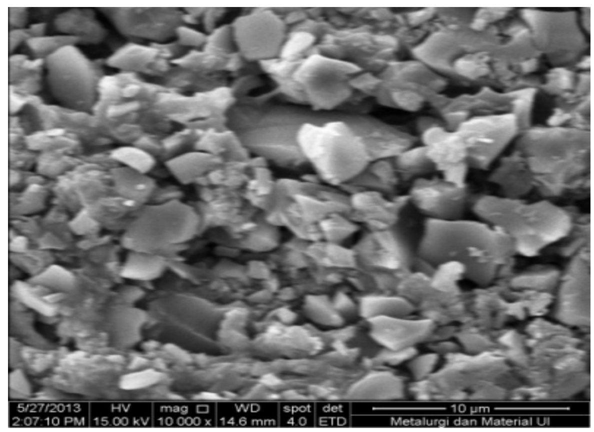
Table-2
The composition of the composite tested by XRD

No	Compound Name	Chemical Formula	Scale Factor	Crystal System
1.	Aluminium Oxyde	Al_2O_3	0,429	Rombohedral
2.	Sodium Aluminium Silicate	$NaAlSi_2O_6$	1,374	Monoclinic
3.	Calcium Magnesium Silicate	$Ca_2MgSi_2O_7$	1,186	Tetragonal
4.	Calcium Aluminium Silicate	$Ca_2(Al(AlSi)O_7$	0,779	Tetragonal
5.	Sodium Calcium Silicate	$Na_4Ca_4O(Si_6\ O_{18})$	0,076	Rombohedral
6.	Carbon	C	0	Orthorhombic

The result of composition measurement by XRD shows that the tested composite consists of Aluminium Oxyde, Sodium Aluminium Silicate, Calcium Magnesium Silicate, Calcium Aluminium Silicate, and Sodium Calcium Silicate in scale factor: 0,429 : 1,374 : 1,186 : 0,779 : 0,076. It shows that percentage of Al_2O_3 : 11,10%, $NaAlSi_2O_6$: 35,55%, $Ca_2MgSi_2O_7$: 30,69%, $Ca_2(Al(AlSi)O_7$: 20,68%, and $Na_4Ca_4O(Si_6\ O_{18})$: 1,97%. Data acquisition by using BET-Quantachrome Nova instrument shows that surface area of the synthesized composite is 5.597 m^2/g, total pore volume for pores with radius less than 1001.11 A at P/P_o = 0,990330 is 2.531 cc/g and average pore radius is 9.044 A. Alleged that the polyvinyl acetate closes the pumice pores and decreases its ability in absorbing noise. The density of the synthesized composite is 1061,045 Kg/m^3 and by using Universal Testing Machines Model 2000E Serial No. 010903 the strength of pressure in average is 12.600,000 N/m^2

It so happens, the results of absorption coeffisien measurement of samples by impedance tube are shown in figure 6.(a) and figure 6(b). Although the pumice was very porous as a raw material, but it is covered by binder after synthesis process and predicted that it causes problem in absorbing noise. The results of measurements with impedance tube of 3 same kinds of samples without resonator is shown in figure-6.(a). If all diameters of samples fit the diameter of tube, they have same pattern of curves as shown in Figure-6(a) at the area below α = 0,12 (vertical axis), but there is anomaly for the sample that has highest peak (above 0,16), it was supposed that the diameter of sampel did not fit the diameter of tube and it caused leakage of energy into the next space in the tube then it made the curve has higher peak. Therefore the curve that has highest peak is not valid curve. Based on the experiment results, the all samples without resonator have high strength, fire resistant after burning them by fire, and water proof after submerging them in the water more than one month, but they does not have a good ability in absorbing noise because the value of absorption coefficient is low. It was alleged that the main factor of the synthesized composite has not a good ability in absorbing noise is that the pumice pores were closed by polyvinyl acetate. Joachim Kinkel (Univ. of Appl. Sci) suggested to use typical glues are high molecular weight polymer like PEG, PVP, Reactive Poly-silicones, TEOS, or Foam Plastics as suggested by Alain Celzard (Univ. of Lorraine) for coping with this case.

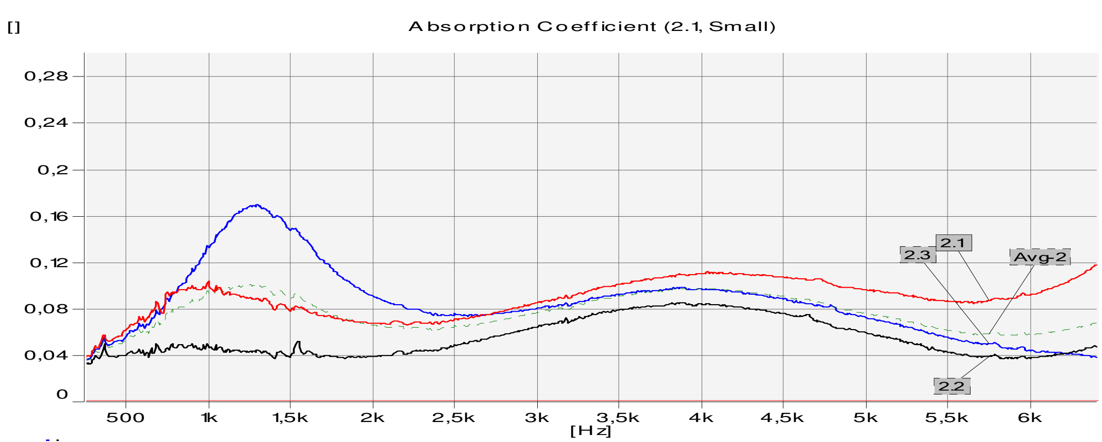
(a)



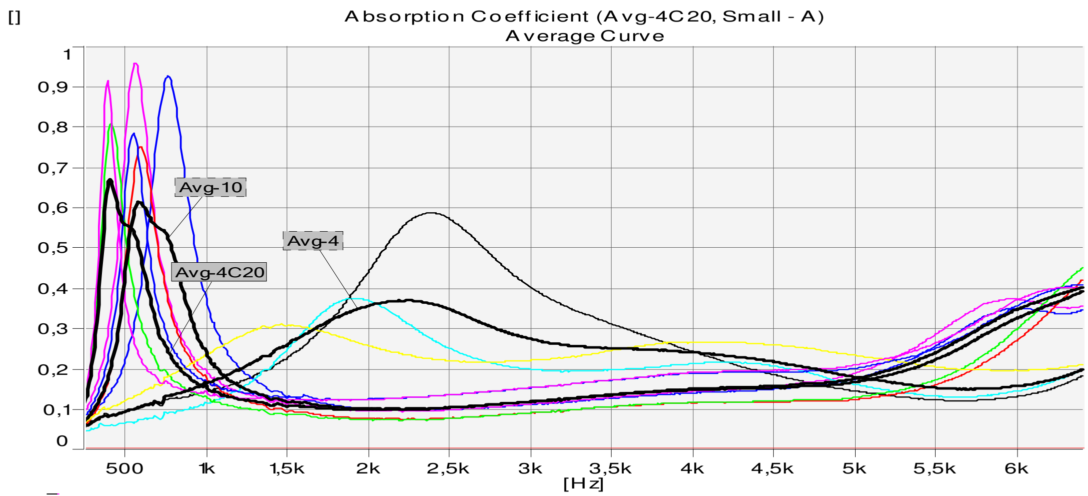
(b)

Figure-5

(a). The tested samples with diameter size 3 cm and thickness 2 cm. b). Morphology of the sample in magnification 10.000 x by SEM



(a)



(b)

Figure-6

(a) Absorption Coeffisien (α) versus Frequency (f) for the composite of Pumice and Al_2O_3 with PVAc as binder without Resonator (Sample No.2); (b) Absorption Coeffisien (α) versus Frequency (f) for the same composite equipped by Quarter Wavelength Resonator and Helmholtz Resonator (Sample No.4)

The measurement results of 3 same samples with resonators are shown in figure 6(b). Every sample equipped by two kinds of resonator: quarter wave length resonator that has diameter size 0,4 cm and depth 2 cm, and Helmholtz resonator that has orifice diameter 0,4 cm, length of neck 2 cm, cavity diameter 3 cm and cavity length was variated : 10 cm and 20 cm. It means that every sample has 3 kinds of curves: one curve from quarter wavelength resonator, one curve from Helmholtz resonator that has cavity length 10 cm, and one curve from Helmholtz resonator that has cavity length 20 cm. The average slightly slope in figure 5(b) shows the absorption caused by quarter wavelength resonator, it has wide bandwidth area but the absorption coefficient only about 0,38, while the high sharp peaks (6 peaks) in the lower frequency area show the absorption caused by two variations of Helmholtz Resonators, they have narrower bandwidth area but the absorption coefficient very high, about 0,9. All acoustic description are based on the original curves (thin curves), while the two black thick curves (Avg 10 and Avg 4C20) both are neglected because not true averaged value. There is a phenomena of ascending curves above frequency 5 kHz in figure 6(b). The main cause of this case is the increasing of viscous mechanism that caused by increasing of energy transfer when the volume of cavity is enlarged, therefore the more energy were absorbed.

Conclusion

The synthesized composite that equipped by Helmholtz Resonator has high absorption coefficient value about 0,9, it effectively absorbs noise especially at low frequency areas below 1000 Hz. It is a good alternative as a building material component for noise absorber especially at low frequencies areas. It has been noted that one of the most important factor in sound absorption of composite materials is the type of binders. Different binders perform different abilities in absorbing noise. By using typical glue that keeps the pores of composite still open, the ability of composite in absorbing noise will be better. The composite fabricated by pumice and Al_2O_3 with polyvinyl acetate as binder equipped by Helmholtz Resonator exhibits a good alternative to be used as a building material component for noise absorber because it is relatively cheap, high strength, light, fire resistant, water proof and simple to produce.

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