Fabrication and Characterization of Basalt Fiber Reinforced Epoxy Laminate for Low Frequency Passive Noise Reduction: Transfer Matrix Approach

SREEJA RAJAPPAN[1*], PREMLET BHASKARAN[2,3] and ROXY. M.S[2,3]

[1]Government Polytechnic College, Kalamassery, Eranakulam, Kerala (India)
[2]S.N. College, Kollam, Kerala, India.
[3]University of Kerala, Thiruvananthapuram, Kerala, (India)
Corresponding author Email:- sreejarajappan87@gmail.com
http://dx.doi.org/10.22147/jusps-B/300701

Abstract

Active and passive noise controlling methods are widely used for noise reduction applications as it is essential to control unwanted noise and vibration which adversely affects human life, wild life, aquatic life and the ecosystem as such. The technological, automobile and biomedical world also prefer noise and vibration free atmosphere for the efficient performance. However, passive noise reduction at lower frequency range is highly challenging due to the unavailability of suitable materials. The emergence of engineered composite materials pave way to this bottle neck problem. Herein, natural fiber composites are synthesized using Vacuum Assisted Resin Transfer Molding and characterized for noise reduction in the low frequency region with the help of transfer matrix method using an impedance tube. The results show that the natural micro fibrous basalt fiber composite is a highly efficient sound absorber in the lower frequency region compared to the glass fiber based one. The fiber radius is critical in tuning the frequency range. The contact angle measurements reveals that the basalt fiber composite is more hydrophobic in nature.

Key words: noise reduction, passive acoustic absorber, acoustic absorption coefficient, transfer matrix, impedance tube.

Introduction

In the present scenario of fast industrialization and technological development noise pollution has become one of the serious issues to be concerned as far as from the increased level of concern about the

environment, ecology and ecosystem. Constant exposure to increased noise above a particular level (85 dB for eight hours) can cause serious health problems in human beings. Hearing impairment, sleep disturbance, high blood pressure, increased stress level, cardiovascular problems and certain anti-social behavioral changes are some of the proven noise induced physical and psychological health issues suffered by human beings[1-3]. Wild animals and aquatic organisms are also victims of noise pollution. Sound pollution induces physical problems as well as certain behavioral changes in wild animals which in turn will adversely affect the full ecosystem by altering the food chain and the combination of species. Marine world is also under threat because of the increased level of sound intensity which alters the natural habitat of the aquatic species and disturbs their normal behavior and life[4-5]. Sophisticated parts of certain high definition instruments are also sensitive to their inbuilt vibration and noise which cause wear and tear to them and thus their smooth functioning is being interrupted. At this juncture noise pollution is a serious matter to be addressed properly in order to have a noise free green environment for the comfortable and healthy functioning of the living and non-living world. Active and passive noise controlling mechanisms are commonly used in this context for this purpose[6]. Even though active acoustic absorbers including electroacoustic absorbers need external energy for their functioning they are efficient in controlling low frequency noise in the frequency region below 2000Hz compared with the passive ones[7]. Passive absorbers are preferred because of their independent performance without the help of external power source and their efficiency in controlling acoustic frequencies in the higher frequency region. Low frequency noise controlling using active absorbers replacing the thick passive ones is also a challenging attempt[8]. As such the necessity to cover the low frequency noise controlling region with the help of energy efficient thin passive absorbers replacing the active noise controllers is relevant in this particular context.

Commonly used passive acoustic absorbers such as porous, non-porous and micro perforated panel absorbers (MPP) have their own specific microstructural properties which enhance the sound absorption mechanisms happening within them. Fibrous, granular and tubular structures existing in porous materials make them efficient passive sound absorbers[9,10,11]. Composite making technology provides a wide opportunity for properly using these peculiar structures of the porous natural as well as synthetic materials for noise reduction applications in the particular frequency region of interest. The variability in the fiber diameter cum length and the possibility in altering their orientation inside a host material make the fibrous materials suitable to be engineered as efficient sound absorbing composites. The low cost natural fibers are proven as efficient reinforcing element in producing a wide variety of useful eco-friendly and biodegradable composites. The low value of their mechanical stiffness, strength and their hydrophilic nature are some of the major concerned designing issues over the synthetic ones[12-13]. Natural fibers obtained from plants, animals, minerals found in nature as well as the synthetic ones which find wide applications in industrial purposes are efficient in acoustic noise reduction applications also because of their inherent properties[14-15]. Some of the prominently used natural fibers in textile industries like cotton, jute, silk, wool, camel hair, flax etc. are effectively utilized in synthesizing passive noise absorbing composites. Bamboo fiber, coconut fiber, kenaf, hemp, bagasse, sisal fiber, date palm fiber etc. are some of the natural fibers commonly used in acoustic insulation applications[16]. According to Delaney Bazely and Johnson Allard model the micro fibrous and lignocellulosic nature of these naturally existing fibers helps in enhancing the sound absorption mechanisms happening within them[17-18]. The availability of the different varieties of natural fibers with desired physical, mechanical cum chemical properties and their wide range of fiber diameters in the micrometer range help in synthesizing passive noise absorbing composites in the desired frequency region of interest[19]. D.J. Oldam et.al reported a peak acoustic absorption close to 1 in the frequency region near 4KHz for cotton fiber reinforced composite sample whereas for jute fiber based one a peak absorption of 0.8 was obtained close to 4kHz and when sisal fiber based composite is tried a very lower value of acoustic absorption is obtained near to 4kHz. The variability in the acoustic response is due to the difference in the fiber diameter and the mechanical properties of the above fibers as reported by Oldham *et.al.*[20]. I. Suhawati *et al*

reported a peak acoustic absorption coefficient of 0.9 at the frequency 3kHz when a rubber based composite is reinforced with kenaf fiber[21]. Whereas when kenaf fiber is incorporated in a polypropylene based composite 100% absorption is obtained at 3.2 KHz as reported by D. V. Parikh *et al.*[22]. The peak acoustic absorption shift to the higher frequency region between 3kHz to 6kHz when hemp fiber is used as a reinforcing element instead of kenaf in another polypropylene based composite[23]. Polymer fibers, carbon fibers, mineral fibers and regenerated natural fibers are widely used in various applications in this current world of technology[24-25]. They are proven as efficient ones in acoustic noise reduction applications also because of the possibility in properly engineering their physical and chemical properties with the help of the recent advancements in the field of nanotechnology and composite making technology[26-28]. In this work glass fiber and basalt fiber based epoxy laminates are prepared and acoustically characterized and compared. Herein we report, the hydrophobic and stable basalt fiber composite prepared by Vacuum Assisted Resin Transfer Molding Technology (VARTM) for sound absorption at low frequency.

Glass fiber- one of the promising industrial materials having silica as its prominent content- is used in this present study to prepare epoxy laminate for sound absorption applications. Glass fibers available in various forms such as yarns, chopped strands, mats and fabrics make it comfortable to be utilized depending on the application of interest. Their inherent physical cum chemical properties such as hardness, chemical inertness, optical transparency, stability etc. make them a versatile material in various fields. The desirable fiber properties of these microfibers such as stiffness, flexibility and strength make them the promising material of interest. Different types of glass fibers like E-glass, S-glass, R-glass, C-glass, D-glass etc. are preferred in making composites for medical, electrical and other industrial purposes[29]. Other than glass basalt fiber reinforced epoxy laminate is also tried and compared its acoustic performance with that of the glass based one. This green ecofriendly natural basalt fiber having peculiar properties of its own make it an innovative one for wide range of applications. As a result of the high mechanical strength, fire retardant nature, chemical inertness, nontoxic and non-carcinogenic nature of these micro fibrous basalt fiber compared to glass and other synthetic fibers it is emerging as a highly promising material of the 21st century[30].

This present investigation focuses on the low frequency noise reduction problem with the help of the natural basalt fiber based epoxy laminate. Three different fiber based acoustic absorbers are synthesized and their acoustic characterization is done so as to shift the maximum acoustic absorption to the low frequency region in order to address the low frequency noise reduction problem with the help of these passive acoustic absorbers. Glass fiber and the natural ecofriendly basalt fiber based porous acoustic absorbers are synthesized and the frequency response of their acoustic absorption coefficient is studied. The shift in the peak absorption coefficient when shifting from glass fiber epoxy laminate to the basalt fiber based one is investigated. The result proves the efficiency of basalt fiber as a strong sound absorber in the low frequency region compared to glass fiber matrix. Our result shows that this material is superior to the low frequency active noise controllers and the passive synthetic acoustic absorbers reported in literature[31-32]. The hydrophobicity of the samples is measured with contact angle measurement unit and acoustic absorption is measured with the impedance tube using the four microphone transfer matrix method.

Sample Preparation using VARTM Technique :
The glass fiber and the basalt fiber based composites used in this study are prepared using the Vacuum Assisted Resin Transfer Molding Technology (VARTM)[33]. Coating wax is applied on the clean and dry mold surface for the easy removal of the composite. The cleaning of the mold surface is done with the help of Acetone. Here 16 layers of mats of basalt fibers weighing 384gm are used for preparing the composite and the sealant tape is placed on surface. Hardener HY951 is mixed with Epoxy LY556 in the ratio 10:1. The resin is sprayed evenly onto the surface of the mold and mixed by hand lay-up. Spiral tube is fitted to Vacuum pump

which was used to vacuum out the air of the system. After peel ply, distribution mesh and vacuum bag were placed. Monitoring and checking is necessary to ensure that there should be no leakage of vacuum. Vacuum-infusion assisted hand lay-up method used in this study offers more benefits than hand lay-up method due to the better fibers to resin bonding resulting in stronger and lighter laminates. Figure.1 shows the schematic diagram of the VARTM set-up. The glass fiber based epoxy laminates are also used for preparing the epoxy laminate in the same way. The sample so prepared is taken out carefully and cut it into circular shape for placing it in the impedance tube for the acoustic characterization. Samples used for the present study are shown in Figure. 2a and Figure. 2b.

Experimental set-up used for acoustic characterization :
            The acoustic characterization of the sample is done using the four pole impedance tube set up shown in Figure.3. The sound signals of varying frequency are sent from one end of the tube to the other one. The sample under test of thickness d is placed at the middle portion of the
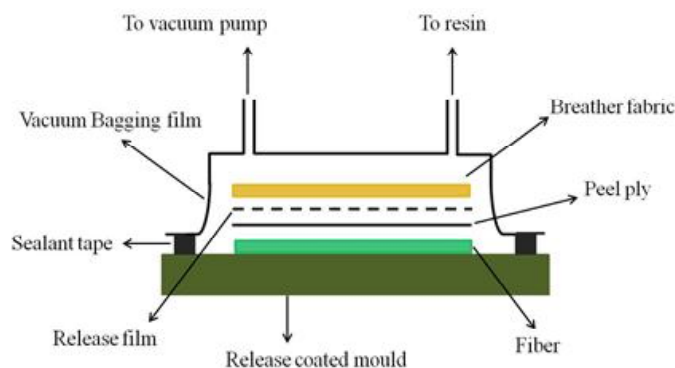

Figure.1. Schematic diagram of the VARTM technique.

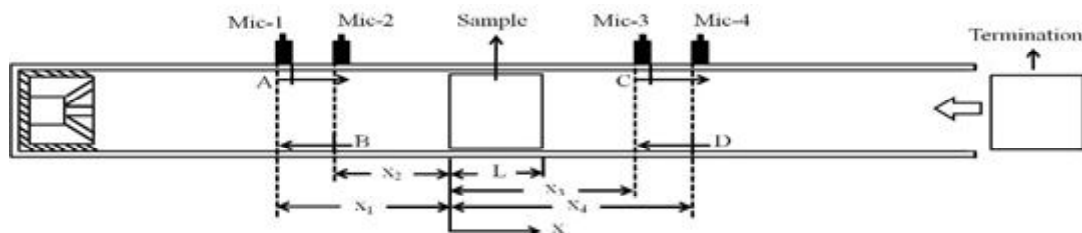Figure. 2a&2b. Glass fiber and Basalt fiber Epoxy Laminate.

Figure.3 Schematic diagram of the Impedance tube apparatus.

impedance tube. The sound signals before entering the sample and after entering the sample p_1 to p_4 are measured at the four microphone positions. Using these values the sound pressure levels on either side of the sample can be determined in terms of the amplitude of the sound signal A, B, C, D at the four microphone positions. These sound pressure levels are related to each other in terms of the transfer matrix T with elements T_{11}, T_{12}, T_{21} and T_{22}. The values of A,B,C,D in terms of the microphone positions x_1 to x_4 and pressure levels p_1 to p_4 are given by equation (1 & 2). The sound signals on either side of the sample at x=0 and x=d in terms of A, B, C, D are given by (3 & 4). The sound pressure and velocity on either side of the sample in terms of transfer matrix and the elements of the transfer matrix are given in equation(5) and equation(6) respectively. The relation between transfer matrix elements and the characteristic impedance are given by equations (7) and (8). The acoustic parameters of the specimen under test can be evaluated once the elements of the transfer matrix are determined. The acoustic reflection and the absorption coefficient of the sample in terms of the elements of the transfer matrix are shown in the equations (9& 10).

$$A = \frac{j\left(P_1 e^{jkx\,2} - P_2 e^{jkx\,1}\right)}{2\sin k(x_1 - x_2)}, \quad C = \frac{j\left(P_3 e^{jkx\,4} - P_4 e^{jkx\,3}\right)}{2\sin k(x_3 - x_4)} \tag{1}$$

Where kp is given by the equation

$$B = \frac{j\left(P_2 e^{jkx\,1} - P_1 e^{-jkx\,2}\right)}{2\sin k(x_1 - x_2)}, \quad D = \frac{j\left(P_4 e^{jkx\,3} - P_2 e^{-jkx\,4}\right)}{2\sin k(x_3 - x_4)} \tag{2}$$

$$P\big|_{x=0} = A + B \quad and \quad P\big|_{x=d} = Ce^{-jkd} - De^{jkd} \tag{3}$$

$$V\big|_{x=d} = \frac{Ce^{-jkd} - De^{jkd}}{\rho c} \quad and \quad V\big|_{x=0} = \frac{A+B}{\rho c} \tag{4}$$

$$\binom{P}{V}\Big|_{x=0} = \begin{pmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{pmatrix} \binom{P}{V}\Big|_{x=d} \tag{5}$$

$$\begin{pmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{pmatrix} = \frac{1}{P|_{x=0}V|_{x=d} + P|_{x=d}V|_{x=0}} \begin{pmatrix} P|_{x=d}V|_{x=d} + P|_{x=0}V|_{x=0} & P|^2_{x=0} - P|^2_{x=d} \\ V|^2_{x=0} - V|^2_{x=d} & P|_{x=d}V|_{x=d} + P|_{x=0}V|_{x=0} \end{pmatrix} \tag{6}$$

In terms of the characteristic impedance k_p the transfer matrix can be expressed as,

$$\begin{pmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{pmatrix} = \begin{pmatrix} \cos k_p d & j\rho c \sin k_p d \\ \frac{j\sin k_p d}{\rho c} & \cos k_p d \end{pmatrix} \tag{7}$$

Where kp is given by the equation

$$k_p = \frac{1}{d}\cos^{-1} T_{11} \tag{8}$$

$$R = \frac{T_{11} - \rho c T_{21}}{T_{11} + \rho c T_{21}} \tag{9}$$

$$\alpha = 1 - |R|^2 \tag{10}$$

Results and Discussion

        The acoustic absorption coefficient of the samples is calculated using the elements of the transfer matrix determined using the sound pressure levels at the four microphone positions. The frequency response

of the acoustic absorption coefficient is determined for the basalt fiber epoxy laminate and glass fiber epoxy laminate. The comparison between the frequency response of acoustic absorption coefficient of glass fiber epoxy laminate and that of the basalt fiber epoxy laminate is shown in Figure.4. In the case of this glass fiber based sample it is possible to shift the acoustic absorption peak to the lower frequency region close to 2000Hz with its acoustic absorption peak at 0.85 (Figure. 4) compared to that of the other reported fiber based acoustic samples[20-23]. When the basalt fiber laminates is tried for its acoustic response its acoustic absorption peak is shifted to a still lower frequency value at 1500 Hz with a higher value of peak absorption at 0.9967 (Figure. 4). Here a shift in the acoustic absorption peak to the lower frequency region with an increase in its value is achieved in this basalt fiber reinforced composite as a result of the decrease in fiber diameter of the basalt fiber compared to that of the glass fiber. The SEM images of the basalt and glass fiber epoxy laminate shown in Figure. 5a & 5b clearly reveal the low fiber diameter of basalt the fiber compared to that of the glass fiber sample used in this study. This result is in accordance with the Delaney Bazeley and Jhonson Allard Model[17-18]. The contact angle measurement of the sample is also done and the results are shown in Figure.6a & 6b. The contact angle for basalt fiber based composite is higher than that of the glass fiber based one and it is less hydrophilic compared to the other one. Hence it is possible to reduce the moisture absorption and to increase mechanical strength cum life time of this natural fiber when it is used in the form of this composite compared to the glass fiber based one. Thus it is successfully synthesized a composite with a high acoustic absorption coefficient of 0.9967 in the lower frequency region of 1500Hz when the natural ecofriendly bio sustainable basalt fiber –the fiber of the 21st century- is used as the reinforcing fiber instead of the glass fiber in preparing the composite material. Thus this passive acoustic absorber can be used for low frequency noise reduction applications replacing the active ones.
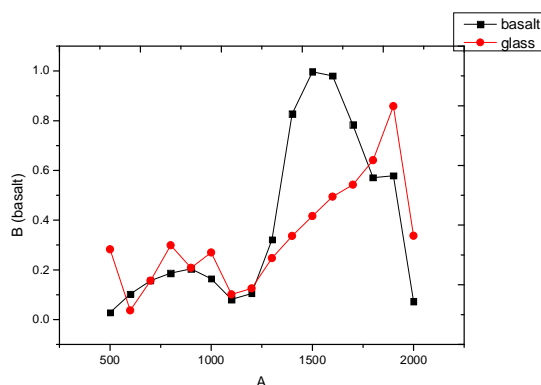

Figure. 4. Comparison of the frequency response of acoustic absorption coefficient of basalt fiber and glass fiber epoxy laminate.
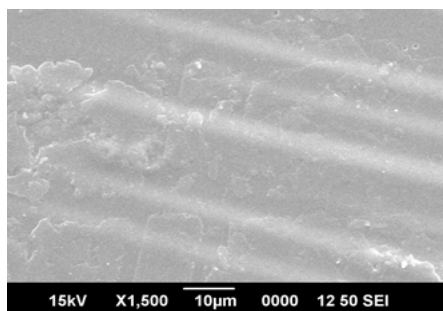

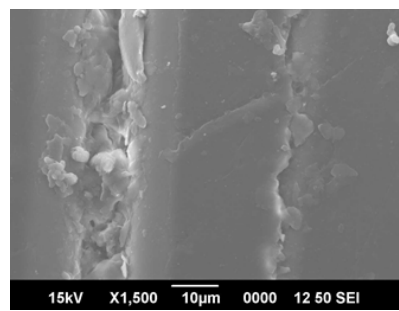Figure. 5a. SEM image of basalt fiber based epoxy laminate.

Figure.5b SEM image of glass fiber based epoxy laminate.

Figure. 6a & 6b Contact angle for glass fiber and basalt fiber composite.

Conclusion

In the present investigation fiber based acoustic materials are prepared and their frequency response of acoustic absorption coefficient is analyzed using transfer matrix analysis with the help of impedance tube. The physical and microscopic structural properties of the fibers are utilized in synthesizing the acoustic absorbers in the desired frequency region of interest. The glass fiber and basalt fiber based acoustic absorbers have their own specific sound absorption peak at the characteristic frequency of their own. The fiber diameter plays a crucial role in determining the acoustic absorption at a particular frequency region. Here a shifting in the maximum acoustic response towards the lower frequency region is obtained when the natural ecofriendly basalt fiber based composite is used. The hydrophilic nature of this natural fiber based composite is less compared to that of the glass fiber based one. Thus it is successful in synthesizing a passive acoustic absorber with low moisture absorbing capacity for low frequency noise reduction applications where only active ones are in use.

Future scope of the work :
This acoustic insulating material should be tested for its thermal, mechanical and dielectric properties in order to optimize an acoustic insulator with good mechanical, thermal insulating and dielectric properties.

Acknowledgement

References

1. Kenneth I Hume, Mark Brink, Mathias Basner., 'Effects of environmental noise on sleep', Noise Health, vol. 14 no. 61, Nov-Dec, pp. 297-302 (2012).
2. Thomas Munzel., Tommaso Gori., Wolfgang Babisch and Mthias Basner., 'Cardiovascular effects of environmental noise exposure', Eur Hear t J, vol. *35* no.13, Apr, pp. 829–836 (2014).
3. Schreckenberg, D., Griefahn,B., Meis, M., 'The associations between noise sensitivity, reported physical and mental health, perceived environmental quality, and noise annoyance', Noise Health, vol.*12* no. 46, Jan-Mar, pp. 7-16 (2010).
4. Oxley, D.J., M.B. Fenton., G.R. Carmody., 'The effects of roads on populations of small mammals', Journal of Applied Ecology, vol. *11,* pp. 51-59 (1974).
5. Trombulak, S.C., C.A. Frissell., 'Review of the ecological effects of roads on terrestrial and aquatic communities', Conservation Biology, vol. *14* no.1, pp. 18-30 (2000).
6. C. A. Gentry, C. Guigou, and C. R. Fuller., 'Smart foam for applications in passive–active noise radiation control', J. Acoust. Soc. Am., vol. *101* no. 1, pp. 1771–1778 (1997).
7. Landaluze, J., I. Portilla., J.M. Pagalday., A. Marti, R., Reyero., 'Application of active noise control to an

elevator cabin', Control Eng. Pract., vol. *11,* pp. 1423-1431 (2003).

8. Steve Wise and Geoff Leventhall., 'Active noise control as a solution to low frequency noise problems', Journal of low frequency noise, vibration and active control, Vol. *29* No. 2, pp. 129 – 137 (2010).

9. Seddeq,H.S., 'Factors influencing acoustic performance of sound absorptive materials', Aust. J. Basic and Applied Sci., vol. 3 no. 4, pp. 4610-4617 (2009).

10. Sreeja Rajappan., Premlet Bhaskaran and Prasanth Ravindran., 'An Insight into the Composite Materials for Passive Sound Absorption', *J. Applied Sci.,* vol. *17* no.7,pp.339-356 (2017).

11. GAURAV MISHRA, RAVINDRA KUMAR and K. K. SINGH., 'Magnetohydrodynamic steady laminar generalized plane couette flow of viscous fluid through porous medium', *Ultra Scientist B*, Vol. *25* no.1, pp. 163-166 (2013).

12. Heng, Jerry, Y. Y., Pearse, Duncan, F., Thielmann, Frank; Lampke, Thomas; Bismarck, Alexander., 'Methods to determine surface energies of natural fibres: a review', Instrumentation Science & Technology, vol.*14* no. 7-9, pp.581–604 (2007).

13. Murugan Rajesh., Jeyaraj Pitchaimani., 'Mechanical Properties of Natural Fiber Braided Yarn Woven Composite: Comparison with Conventional Yarn Woven Composite', Journal of Bionic Engineering,vol.*14* no. 1, pp. 141–150 (2017).

14. Maya Jacob John., Sabu Thomas., 'Biofibres and biocomposites', Carbohydrate Polymers,vol.*71* no.3,pp. 343–364 (2008).

15. Marguerite Rinaudo., 'Chitin and chitosan: Properties and applications', Progress in Polymer Science, vol.*31* no.7, pp. 603–632 (2006).

16. Arenas, J.P., M.J. Crocker., 'Recent trends in porous sound-absorbing materials', Sound Vibr.,vol. *44* no. 7, pp. 12-18 (2010).

17. Delany, M.E., E.N. Bazley., ' Acoustical properties of fibrous absorbent material', Applied Acoust., vol. *3,* pp. 105-116 (1970).

18. Champoux, Y. and Allard, J.F., 'Dynamic tortuosity and bulk modulus in air-saturated porous media', *J Appl. Phys.,* vol. *70* no.4, pp. 1975–1979 (1991).

19. K.L. Pickeringa, M.G. Aruan Efendy, T.M.Le., 'A review of recent developments in natural fibre composites and their mechanical performance', Composites Part A, vol. *83,* April, pp. 98-112 (2016).

20. DJ Oldham, CA Egan, RD Cookson., 'Sustainable acoustic absorbers from the biomass', Applied Acoustics, vol. *72,* pp. 350-363 (2011).

21. Suhawati, I., K. Shamsul, I. Ismaliza , A.M. Kamarudin., 'Sound absorption analysis of foamed rubber composites from kenaf and calcium carbonate', J. Rubber Res., vol. *16,* pp. 36-44 (2013).

22. Parikh, D.V., Y. Chen and L. Sun., 'Reducing automotive interior noise with natural fiber nonwoven floor covering systems', Textile Res. J., vol. *76* no.11, pp. 813-820 (2006).

23. Markiewicz, E., D. Paukszta and S. Borysiak., 'Acoustic and Dielectric Properties of Polypropylene-Lignocellulosic Materials Composites In Polypropylene, Dogan, F. (Ed.). Intech, USA., pp: 193-218 (2012).

24. Biercuk, M. J., Llaguno, M. C., Radosavljevic, M., Hyun, J. K., Johnson, A. T., Fischer, J. E., 'Carbon nanotube composites for thermal management', Applied Physics Letters , vol. *80* no. 15, pp. 2767-2769 (2002).

25. Dalton, A.B., Collins, S., Munoz, E., Razal, J.M., Ebron,V.H., Ferraris, J.P., Coleman, J.N., Kim, B.G., Baughman, R.H., 'Super-tough carbon-nanotube fibres', Nature, vol. *423* no. 6941, pp. 703-703 (2003).

26.   Youngjoo Na, Tove Agnhage, and Gilsoo Cho., 'Sound Absorption of Multiple Layers of Nano fiber Webs and the Comparison of Measuring Methods for Sound Absorption Coefficients', Fibers and Polymers, vol. *13* no.10, pp. 1348-1352 (2012).

27.   M.A. Navacerrada, P. Fernandez, C. Diaz, A. Pedrero., ' Thermal and acoustic properties of Aluminium foams manufactured by infiltration process', Applied acoustics, vol. *74,* pp. 496-501 (2013).

28.   Duan Cuiyun, Cui Guang, Xu Xinbang, Liu Peisheng., ' Sound absorption characteristics of a high-temperature sintering porous ceramic material', Applied Acoustics, vol. *73* no. 9, pp. 865–871 (2012).

29.   Alexandre Landesmann, Carlos Alexandre Seruti, Eduardo de Miranda Batista., 'Mechanical Properties of Glass Fiber Reinforced Polymers Members for Structural Applications Materials Research', vol. *18* no. 6, pp. 1372-1383 (2015).

30.   Yihe Zhang, Chunxiao Yu, Paul K. Chu, Fengzhu Lv, Changan Zhang, Junhui Ji , Rui Zhang, Heli Wang., 'Mechanical and thermal properties of basalt fiber reinforced poly(butylene succinate) composites',Materials Chemistry and Physics,vol.*133* no.2-3,pp.845–849 (2012).

31.   Landaluze, J., I. Portilla, J.M. Pagalday, A. Marti and R. Reyero., 'Application of active noise control to an elevator cabin', Control Eng. Pract., vol. *11*, pp.1423-1431 (2003).

32.   Ko, Y.H., H.T. Son, J.I. Cho, C.S. Kang., I.H. Oh *et al.*, Investigation on the sound absorption and transmission for aluminum foam and its composite, Solid State Phenomena, vol. 124-126, pp.1825-1828 (2007).

33.   Hayward, J.S. and Harris, B., 'The Effect of Vacuum Assistance in Resin Transfer Molding', Composites Manufacturing, vol. *1,* pp. 161-166 (1990).