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Acoustic characterization of additive manufactured layered porous materials

Akiwate, Deepak[1]
Indian Institute of Technology Hyderabad
Mechanical and Aerospace Engineering, IIT Hyderabad
Kandi, Sangareddy, Telangana. India 502285

Mohan, Shashi Ranjan[2]
Indian Institute of Technology Hyderabad
Mechanical and Aerospace Engineering, IIT Hyderabad
Kandi, Sangareddy, Telangana. India 502285

B, Venkatesham[3]
Indian Institute of Technology Hyderabad
Mechanical and Aerospace Engineering, IIT Hyderabad
Kandi, Sangareddy, Telangana. India 502285

S, Suryakumar [4]
Indian Institute of Technology Hyderabad
Mechanical and Aerospace Engineering, IIT Hyderabad
Kandi, Sangareddy, Telangana. India 502285

ABSTRACT

In the present study, acoustic properties of layered porous materials produced by Fused Filament Fabrication (FFF) technique of Additive Manufacturing (AM) have been investigated. The porous materials are fabricated by using different infill percentage of materials in the direction of fabrication, which leads to layered porous material of various pore sizes along the direction of fabrication. Samples with different combinations of infill percentages are fabricated, and their sound absorption coefficient is measured by using two microphone impedance tube technique. Measured results indicate that the sound absorption coefficient of additive manufactured porous materials can be tuned to the required frequency range by changing the combination of infill percentages. The results and fabrication technique presented here gives an alternative method to fabricate layered porous materials.

Keywords: Layered porous materials, Additive manufacturing, Absorption coefficient
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[1] me14resch11001@iith.ac.in
[2] me14resch11010@iith.ac.in
[3] venkatesham@iith.ac.in
[4] ssurya@iith.ac.in

1. INTRODUCTION

Porous materials are widely used as sound absorbing materials along the path of wave propagation in many engineering fields like automobile, aviation, and building design etc. [1]. The traditional sound absorbing materials include glass wool, polymer foams, mineral fibers which can be made to adopt any complex shapes. However, these materials have environmental concerns such as non-degradability and high human health risk factors [2, 3]. As alternatives, there are studies which explore natural materials as acoustic absorbing materials like coconut core fibers, jute, luffa fibers, rice straws, and waste developed during processing of tea leaves etc. [4-8]. While they are environment-friendly, the acoustic properties of natural materials depend on both sample considered as well as production processes involved which may not guarantee reproducibility and vary for different fibers or production processes. Researchers are also exploring other materials like porous copper, poly (ethylene-co-octene) foam, open-cell polyolefin-based foams, and structures with micro-sized open cells of ceramic hollow spheres [9-12]. However, these materials do not lend themselves easily to complex shapes and patterns and would require significant research to mature into a deployable technology. The recent advances in Additive Manufacturing (AM) provide an alternative method for precise and controlled fabrication of complex shapes and can be utilized to produce porous structures for acoustic applications [13-15].

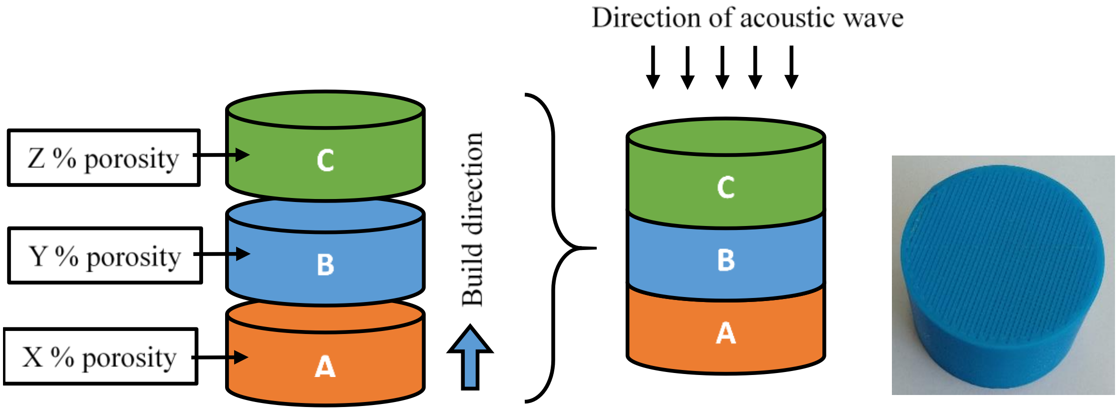
Though there are several studies describing acoustic properties of various materials with different manufacturing methods [4-15], the acoustic properties of micro-porous ABS structure fabricated by extrusion-based Fused Filament Fabrication (FFF) technique of AM have not been studied. FFF technique is arguably the most economical and widespread amongst the various AM processes today. In this work, the acoustic properties of additive manufactured micro-porous ABS material is studied and feasibility of AM to fabricate acoustic porous structure is demonstrated. The results presented in this work lay the foundation to design and fabricate porous structures for acoustic applications.

2. MATERIALS AND EXPERIMENTAL SETUP

2.1 Materials and Samples Fabrication

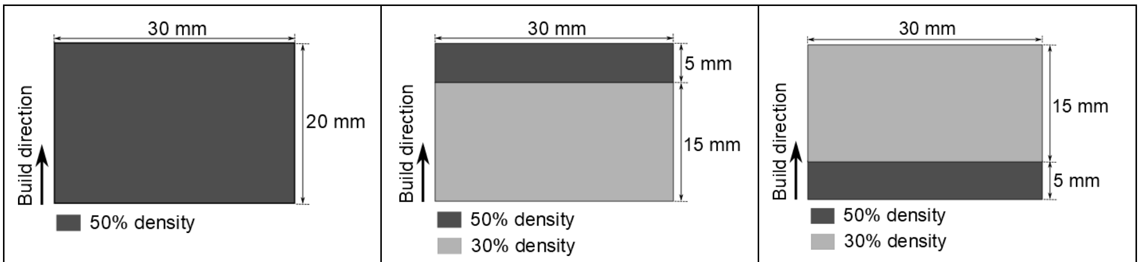
In this study, the samples with variable porosity were fabricated through extrusion-based additive manufacturing (AM) process to observe their acoustic behavior. Here, Acrylonitrile butadiene styrene (ABS) polymer material was used to fabricate the cylindrical samples of 30 mm diameter and 20 mm height using Fused Filament Fabrication (FFF) technique on OpenSouce, RepRap based, Protocenter999 3D printing machine. An ABS Filament of 1.75 mm diameter was extruded through the nozzle having 0.5 mm diameter at 230^0 C temperature while the bed temperature was kept at 100^0 C during the fabrication. The layer thickness was 0.3 mm and the in-fill pattern was rectilinear. The density of this infill pattern would influence the size of the square pores resulting from the in-fill, as shown in Fig.1(b).

The samples of variable porosity along build direction was fabricated by arranging sliced G-code of different infill density in the required sequence. The generalized fabrication methodology has been illustrated in Fig. 1. Hence the sample has three different segments viz., A, B, and C. These have been sliced with three different infill densities X% Y% and Z%, respectively. This stacking of three segments results into variable porosity along the direction of fabrication. This is like traditional stacking of different porous materials in a layered configuration. In this study, one sample with 50% of uniform infill density and five samples of varying density along the length of fabrication were produced. To maintain consistency in the measurements and efficiency analysis, the total length and weight of all the samples was kept constant. Hence, the total lengths for 50% and 30 % infill densities were maintained at 5 mm and 15 mm. Different samples vary in the manner of their spread of these densities. The different configurations for uniform and non-uniform porosity are shown in Fig. 2. Figure 2(a) shows the sample with 50% uniform density, while Fig. 2(b-f) represents the configuration for non-uniform porosity.

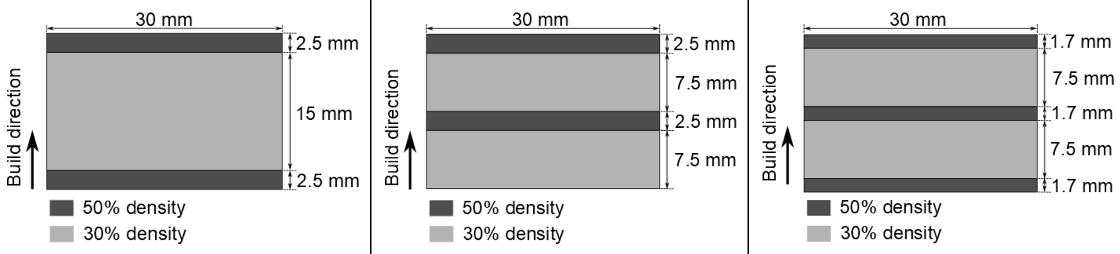


(a) (b)

Fig. 1 (a) Generalized fabrication methodology of proposed variable porous material (b) Image of a fabricated sample



(a) ADM 50 (b) ADM 50_30 (c) ADM 30_50



(d) ADM 50_30_50 (e) ADM 50_30_50_30 (f) ADM 50_30_50_30_50

Fig. 2 samples having variable porous material along build direction

2.2 Measurement Setup

The normal sound absorption coefficient of AM fabricated porous structures is measured by using impedance tube technique as shown in Fig. 3. The standard two-microphone transfer function method is used for measurement which follows ASTM

1050 [16]. Impedance tube consists of a tube-like structure with the speaker at one end while rigid termination at another end. The impedance tube of 30 mm internal diameter covering the frequency range of 800 to 6300 Hz was used for measurement of absorption coefficient. Random noise was generated using speaker and pressure were measured at two positions along length of the impedance tube. Measured pressures from microphone were further post-processed to separate incident and reflected wave using the transfer function method. Experiments were carried out at laboratory conditions at a temperature of 29^0 C and relative humidity of 50%. Speed of sound and air density at prescribed conditions were 343 m/s and 1.2 kg/m^3, respectively. Measurement sound pressure was maintained at least 10 dB higher than the background noise to minimize the errors during measurement. In addition, error due to phase mismatch of microphones was minimized by using the microphone switching method.

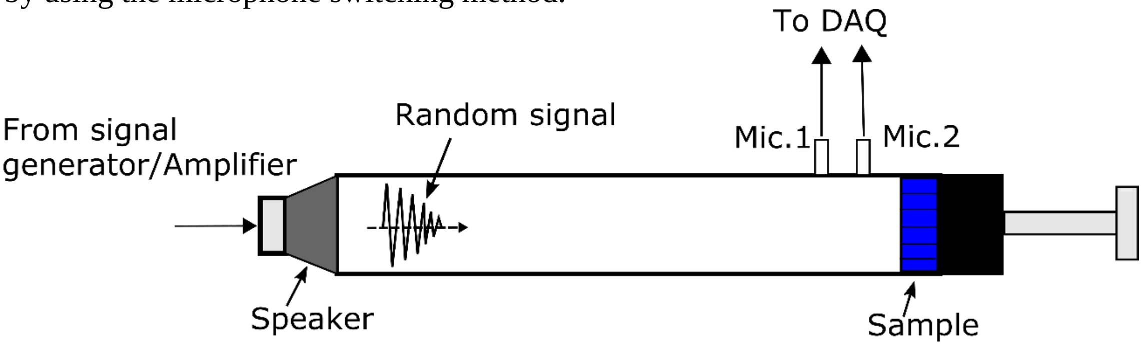
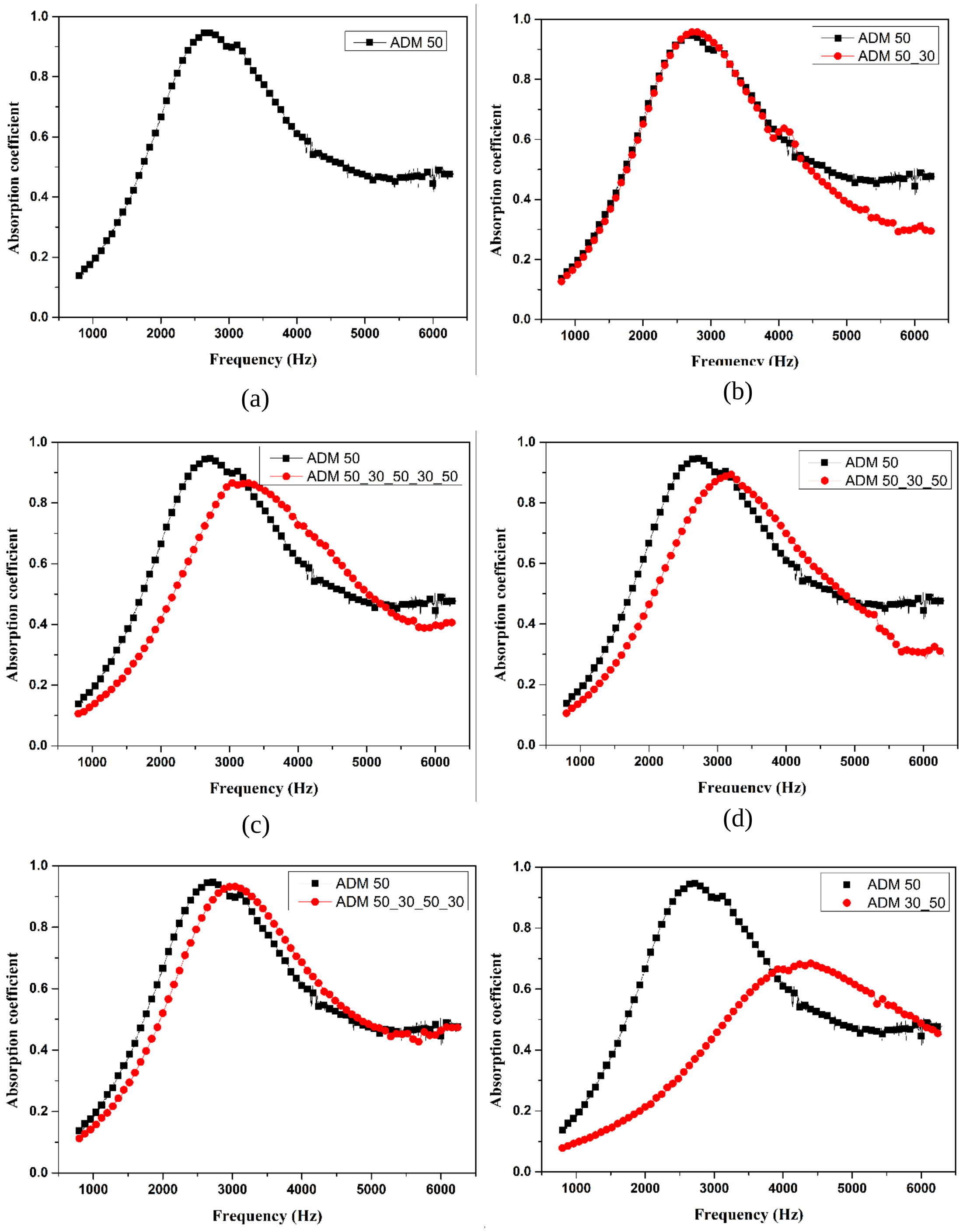


Fig.3 Impedance tube measurement setup for acoustic absorption coefficient

3. RESULTS AND DISCUSSION

The normal sound absorption coefficient of AM samples was measured in impedance tube using two microphone transfer function method and are shown in Fig. 4 and Fig. 5. Absorption coefficient of ADM 50 which is having uniform porosity along the direction of wave propagation is shown in Fig. 4(a). Results show that it has a peak absorption coefficient around 2500 Hz, also has a wider absorption coefficient over the frequency range of 1500-6300 Hz which is one of the desirable properties of acoustic materials. In addition, this porous structure has relatively higher mechanical strength than that of traditional foam material which is one of added advantage and also can accommodate complex shapes as the manufacturing process involves AM. The broadband sound absorption mainly occurs due to the visco-thermal dissipation in narrow pores of the structure. These visco-thermal effects substantially reduce the speed of sound in material compared to that of air and help to achieve good absorption coefficient.

To achieve good absorption coefficient with the relatively lower weight of sample and also to tune it for different frequency ranges, layered porous (variable porosity) materials were manufactured and tested in an impedance tube. Figure 4(b-f) shows a comparison of the measured sound absorption coefficient of variable porosity samples with uniform porosity sample ADM 50. To achieve variable porosity, combinations of 50% and 30% infill percentages were used as shown in Fig. 2 which results in comparatively lower weight (6.45 gram) of a sample than the uniform porosity sample ADM 50 (8.15 gram). From results, it can be observed that ADM 50_30 configuration gives a similar absorption coefficient as that of ADM 50 except at higher frequency above 4500 Hz. This is because 50% infill density which gives smaller pores of size are facing to the source, while the inside section has 30% infill density with relatively larger pore size. Therefore, there will be more entrapped air behind the smaller pores which gives



(a) (b)

(c) (d)

(e) (f)

Fig.4 Measured sound absorption coefficient of fabricated porous structures (a) ADM 50 (b) ADM 50 vs ADM 50_30 (c) ADM 50 vs ADM 50_30_50_30_50 (d) ADM 50 vs ADM 50_30_50 (e) ADM 50 vs ADM 50_30_50_30 (f) ADM 50 vs ADM 30_50

better absorption coefficient. In contrary to that for ADM 30_50 (see Fig. 4(e)), 30% infill is facing to the source while 50% infill is behind which gives relatively poor absorption coefficient with peak frequency of absorption shifting to the higher side. ADM 50_30_50_30_50, ADM_50_30_50, and ADM 50_30_50_30 have similar effects on absorption coefficient where there is a slight reduction in peak absorption coefficient amplitude and also the peak frequency of maximum absorption is shifted to the higher side.

Figure 5 shows comparison of the measured absorption coefficient for layered (variable porosity) porous samples. Results show that sample ADM 50_30 with maximum back entrapped air has better absorption coefficient compared to others. Therefore, it has been clear that the entrapped air behind the narrow pores helps to improve the absorption coefficient. In conclusion, additively manufactured layered porous materials can be tuned to achieve good absorption coefficient in the interested frequency range by changing the infill material percentage along the direction of wave propagation with relatively lower weight.

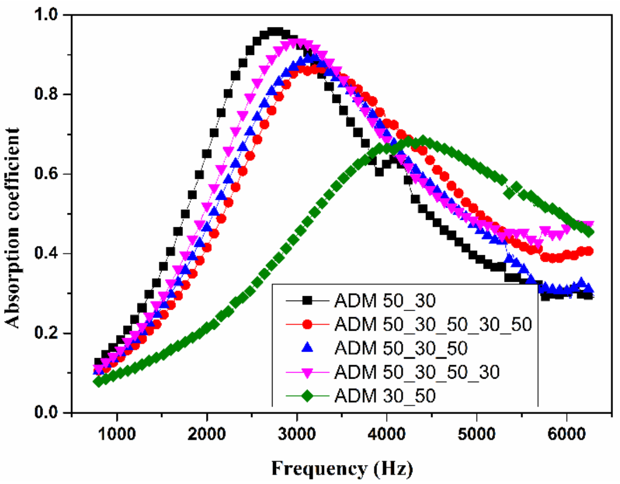


Fig. 5 Comparison of measured absorption coefficients of fabricated variable porosity structures

4. CONCLUSIONS

The present work demonstrated capability of additive manufacturing method based on fused filament fabrication to produce porous structures of uniform as well as varying porosity (layered structure) for acoustic applications. The manufactured samples have broadband sound absorption coefficient over a large frequency range which is amongst the desirable properties of acoustic materials. In addition, it has been observed that structures with non-uniform porosity produce similar absorption coefficient over a wide frequency range as a uniform porosity structure for comparatively less weight. The fabricated structures can also be tuned to the desired frequency range by changing the sequence of material infill percentage along the direction of wave propagation. As the fabrication of structure involves AM, it is quite possible to produce these structures to accommodate any complex shapes and becomes one of the alternatives to traditional porous materials.

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6. REFERENCES

1. I. Vér and L. Beranek, "*Noise and Vibration Control Engineering: principles and applications,*" John Wiley and Sons, Inc., 2005.

2. F. Asdrubali, S. Schiavoni, and K. V Horoshenkov, "*A Review of Sustainable Materials for Acoustic Applications,*" Build. Acoustics. ·, vol. 19, no. 4, pp. 283–312, 2012.

3. S. V. Joshi, L. T. Drzal, A. K. Mohanty, and S. Arora, "*Are natural fiber composites environmentally superior to glass fiber reinforced composites?,*" Compos. Part A Appl. Sci. Manuf., vol. 35, no. 3, pp. 371–376, 2004.

4. R. Zulkifli, M. J. Mohd Nor, M. F. Mat Tahir, A. R. Ismail, and M. Z. Nuawi, "*Acoustic properties of multi-layer coir fibres sound absorption panel*," J. Appl. Sci., vol. 8, no. 20, pp. 3709–3714, 2008.

5. S. Ersoy and H. Küçük, "*Investigation of industrial tea-leaf-fibre waste material for its sound absorption properties*," Appl. Acoust., vol. 70, no. 1, pp. 215–220, 2009.

6. S. Fatima and A. R. Mohanty, "*Acoustical and fire-retardant properties of jute composite materials*," Appl. Acoust., vol. 72, no. 2–3, pp. 108–114, 2011.

7. H. S. Yang, D. J. Kim, and H. J. Kim, "*Rice straw–wood particle composite for sound absorbing wooden construction materials*," Bioresour. Technol., vol. 86, pp. 117–121, 2003.

8. H. Koruk and G. Genc, "*Investigation of the acoustic properties of bio luffa fiber and composite materials,*" Mater. Lett., vol. 157, pp. 166–168, 2015.

9. J. Ru, B. Kong, Y. Liu, X. Wang, T. Fan, and D. Zhang, "*Microstructure and sound absorption of porous copper prepared by resin curing and foaming method*," Mater. Lett., vol. 139, pp. 318–321, 2015.

10. T. Zhao, M. Yang, H. Wu, S. Guo, X. Sun, and W. Liang, "*Preparation of a new foam/film structure poly (ethylene-co-octene) foam materials and its sound absorption properties*," Mater. Lett., vol. 139, pp. 275–278, 2015.

11. M. Álvarez-Láinez, M. A. Rodríguez-Pérez, and J. A. De Saja, "*Acoustic absorption coefficient of open-cell polyolefin-based foams*," Mater. Lett., vol. 121, pp. 26–30, 2014.

12. G. Wu, R. Li, Y. Yuan, L. Jiang, and D. Sun, "*Sound absorption properties of ceramic hollow sphere structures with micro-sized open cell*," Mater. Lett., vol. 134, pp. 268–271, 2014.

13. Z. Liu, J. Zhan, M. Fard, and J. L. Davy, "*Acoustic properties of a porous polycarbonate material produced by additive manufacturing*," Mater. Lett., vol. 181, pp. 296–299, 2016.

14. D. C. Akiwate, M. D. Date, B. Venkatesham, and S. Suryakumar, "*Acoustic properties of additive manufactured narrow tube periodic structures*," Appl. Acoust., vol. 136, pp. 123–131, 2018.

15. D. C. Akiwate, M. D. Date, B. Venkatesham, and S. Suryakumar. "*Acoustic measurement of additive manufactured concentric tube reverse flow resonators,"* Mechanics of Advanced Materials and Structures, pp. 1–6, 2018.

16. A. E-1050, "*Standard Test Method for Impedance and Absorption of Acoustic Materials using a Tube two Microphones and a Digital Frequency Analysis System*," Am. Soc. Test. Mater., pp. 1–12, 1998.