Experimental Investigation of Sound-Absorbing Material of Different Surface Shapes on Noise Reduction Performance of an Acoustic Enclosure

Pavan Gupta and Anand Parey

1 Introduction

Noise pollution of the factory and the industrial workspace is a serious concern. The environment of intense noise plays a major role in a worker's performance. The high exposure to noise not only impacts the adverse effects on psychological health but also causes hearing damage, poor voice communication, and impaired efficiency [1]. The noise generated from cutting tools during machining is one of the main sources of noise in the factory workspace such as portable saw, spindle, drilling machine [2–4]. The acoustic enclosure is one of the most important engineering designed structures for modifying the sound transmission path and suppressing the airborne noise effectively by adding sound-absorbing materials [5]. Cole et al. [6] and many other researchers [7–10] demonstrated theoretically and experimentally the effectiveness of acoustic absorbing materials on the noise reduction characteristics for the acoustic enclosure made of different materials. Recently, Cao et al. [11] and several other researchers [12–14] predicted analytically and experimentally the noise reduction capability of complex structures by incorporating the acoustic absorbing materials in the studies.

The literature survey has shown that the implementation of sound-absorbing materials has a significant role in the noise control of an enclosure and other complex structures. Airborne noise transmission can be diminished by adding the sound-absorbing material which is directly linked with the energy of the acoustic waves. The noise reduction performance of acoustic enclosure depends on many factors such

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P. Gupta (✉) · A. Parey
Discipline of Mechanical Engineering, Indian Institute of Technology Indore, Indore, Madhya Pradesh 453552, India
e-mail: phd1701203006@iiti.ac.in

A. Parey
e-mail: anandp@iiti.ac.in

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as material, geometry, panel thickness, location of the source, the thickness of sound-absorbing material, and location of the implementation of acoustic material on the structure. However, it has been found that limited work is focused on the use of sound-absorbing material with different surface shapes on the acoustical performance of the cutting tool enclosure. By optimization of acoustic material properties in a defined range of frequency, it is possible to maximize the noise reduction of the structure by making use of an adequate amount of sound-absorbing material of different surface shapes. In the current study, therefore, an experimental work is presented for investigating the influence of sound-absorbing material of different surface shapes for the applications of improving the acoustic performance of the cutting tool enclosure. The polyurethane foam (PU) is considered as a sound-absorbing material in the present study. The commercially available acoustic material of three surface shapes, i.e., plane, wedge, and pyramid surfaces are chosen for the analysis.

2 Methodology

The acoustic enclosure performance is defined by noise reduction. The noise reduction (NR) of the acoustic enclosure is expressed in decibel (dB) as follows [15]:

$$NR = L_{\mathrm{O}} - L_{\mathrm{W}}, \tag{1}$$

where L_{O} is the sound pressure level from an unenclosed noise source and L_{W} from the enclosed noise source.

The various commercially acoustic materials used in the experimental work are shown in Fig. 1. The technical properties of acoustic material are given in Table 1.

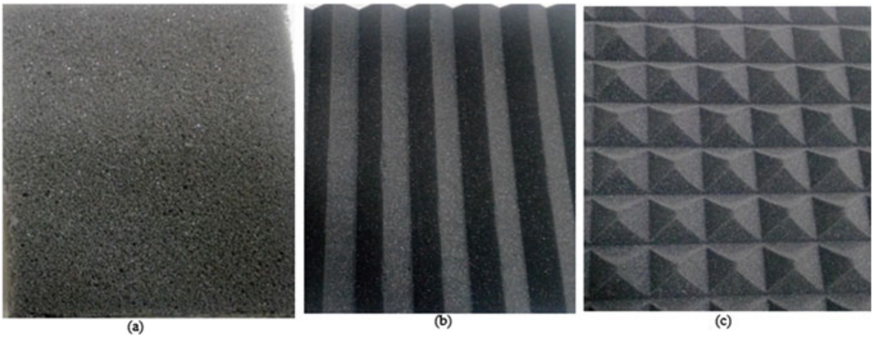


Fig. 1 Polyurethane sound-absorbing material of various shapes **a** plane **b** wedge **c** pyramid

Table 1 Technical properties of acoustics foams available from suppliers

Sl. No.	Parameters	Plane shape PU foam	Wedge shape PU foam	Pyramid shape PU foam
1	Thickness (mm)	50	50	50
2	Bulk density (kg/m^3)	32	32	32
3	Bulk Poisson's ratio	0.39	0.39	0.39

Table 2 Different conditions of noise measurement

Condition	Noise measurement condition details
Case-1	Enclosed source
Case-2	Enclosed source by adding plane shape PU foam
Case-3	Enclosed source by adding wedge shape PU foam
Case-4	Enclosed source by adding pyramid shape PU foam

The initial noise level of the noise sources was measured without an enclosure to have a reference value for comparison purposes. Thereafter, all the iterations have been implemented as per Table 2.

3 Experimental Work

The noise measurement was conducted in a large volume of noise and vibration control laboratory at IIT Indore.

An enclosure made of steel material was employed in the experimental work which consisted of five flexible panels welded together. The enclosure has dimensions of 1 m × 0.8 m × 1 m, and the thickness of each panel was 1.15 mm. The polyurethane foam of different shapes was used in the study. Four piezotronics microphones (PCB made) were employed around the enclosure. The sound pressure level (SPL) measurement is taken at a distance of 1 m for each surface of the enclosure. The spatial mean average value of the sound pressure level was taken. The measurement data was acquired using the 16 channel LMS data acquisition system in the range of frequency between 63 and 8000 Hz of 1/3 octave band.

Noise radiated by the cutting tools is the prime cause of noise pollution in the factory environment. In the present study, therefore, hand-held circular saw of model GKS 7000 with a rated power input of 1100 W is considered as a noise source for the experimental work which is shown in Fig. 2. The sound pressure level value of the noise source is measured to be 88.75 dB(A). The background noise was measured to be 45 dB(A) which is far lesser than the sound pressure level of the noise source. Therefore, background noise has a negligible influence on the noise measurement

Fig. 2 Noise source: handheld circular saw

of the source. All the measurements were repeated for ensuring the reliability of measurement.

The measurement set-up and schematic diagrams for the implementation of PU foam are shown in Figs. 3 and 4, respectively.

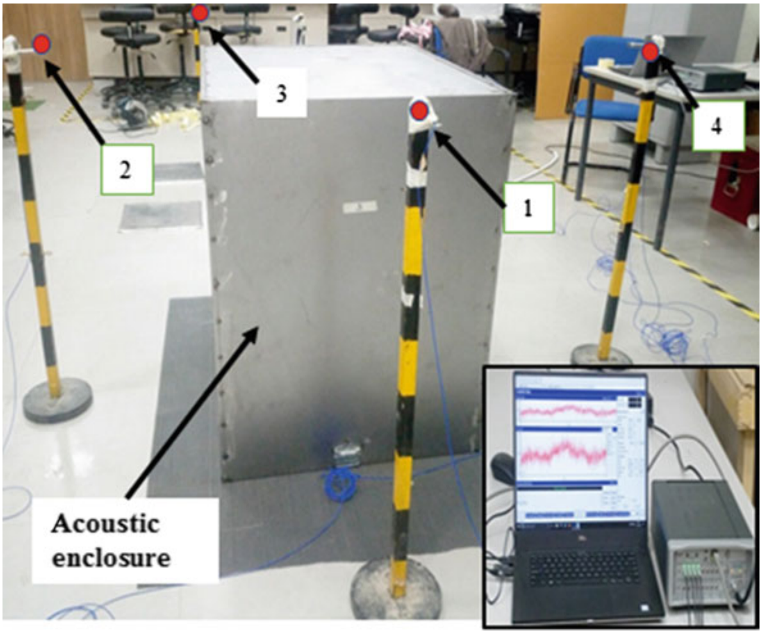


Fig. 3 Experimental set-up using microphones (1–4) with LMS data acquisition system and noise source inside the enclosure

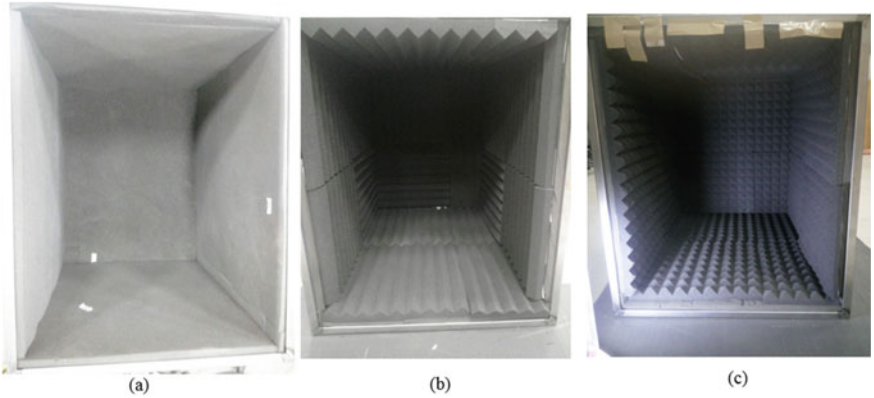

(a) (b) (c)

Fig. 4 Schematic diagrams for the implementation of PU foam: **a** Enclosed source by adding plane shape PU foam, **b** enclosed source by adding wedge shape PU foam, **c** enclosed source by adding pyramid shape PU foam

4 Results and Discussion

The overall SPL values in various cases of the measurement are shown in Fig. 5. It is observed from Fig. 5 that adding the sound-absorbing PU foam inside the enclosure reduces the noise-level efficiently. The acoustic materials not only suppress the acoustic resonance inside the enclosure but also demise the magnitude of standing waves with an increment of the frequencies of the resonance of the standing wave. It can be seen from Fig. 5 that surface shapes of the acoustic material inside the enclosure directly influence the acoustical performance of the enclosure. The overall value of SPL for the noise source was observed is 88.75 dB(A) which is maximum. The minimum SPL is achieved in the case of using pyramid shape PU foam which is 65 dB(A).

The noise reduction for various conditions is shown in Fig. 6. It is found that adding a pyramid shape PU foam inside the acoustic enclosure causes a larger noise attenuation of 23.75 dB(A).

Fig. 5 Overall sound pressure level values of various measurement conditions

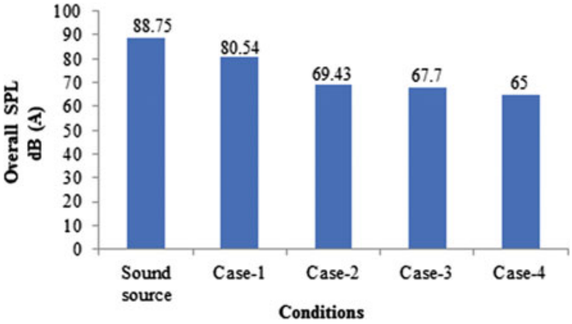
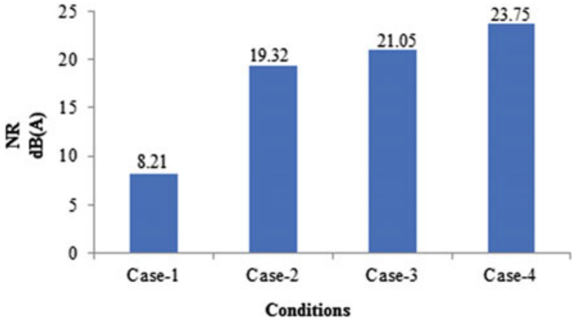


Fig. 6 Noise reduction values of various measurement conditions



It can be observed directly from Fig. 6 that the plane shape and wedge shape PU foams cause a noise reduction of 19.32 dB(A) and 21.05 dB(A), respectively.

The 1/3 octave analysis is carried out to study the effect of various shapes of acoustic material in the different frequency bands [6, 12]. The 1/3 octave analysis shows that wedge shape and pyramid shape acoustic materials have an overall better effect in comparison to plane PU foam in the entire frequency region as shown in Fig. 7. One-third octave band analysis shows that the wedge and pyramid shape PU foams have a similar effect in the frequency range between 500 and 2000 Hz. The pyramid shape PU foam is very efficient in the high-frequency region between 2000 and 8000 Hz. It is clear from the experimental results that the pyramid shape PU foam is very effective for improving the acoustic performance of the enclosure.

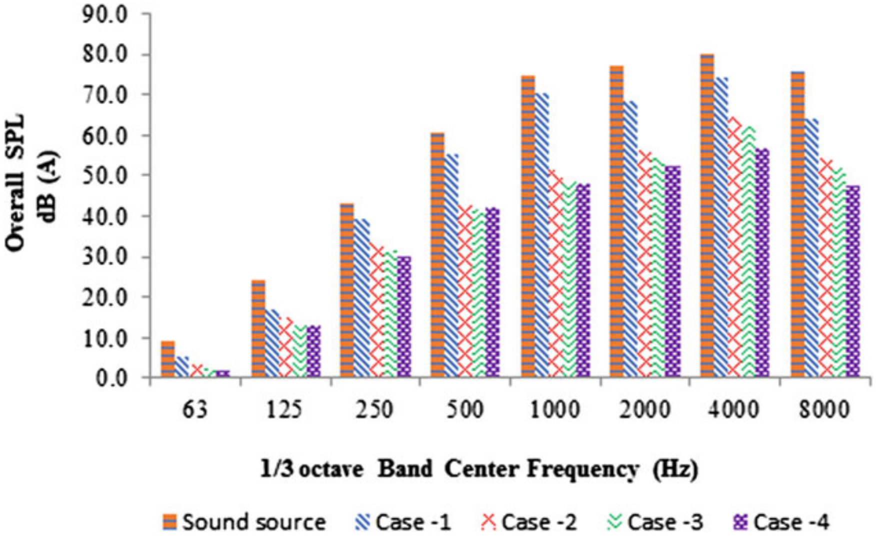


Fig. 7 Overall sound pressure level values at the center frequency of 1/3 octave band

5 Conclusion

Noise control of the factory workspace is a serious issue. The noise generated from cutting tools during machining is one of the main sources of noise in the factory workspace such as portable saw, spindle, drilling machine. The surroundings of intense noise radiated from the cutting tool and machining operations impact directly on the worker's performance. Therefore, an appropriate design of the cutting tool enclosure using sound-absorbing material is imperative from the acoustical point of view.

In the present paper, an experimental study in the laboratory was carried out for investigating the effect of various shape acoustic materials on the noise reduction efficiency of an enclosure for cutting tools applications. The noise source was considered as a handheld saw. The various conditions have been considered for the measurement by using the different shapes of sound-absorbing polyurethane foam. Therefore, commercially available acoustic material of three surface shapes, i.e., plane, wedge, and pyramid surfaces, are chosen for the analysis. It is found from the experimental results that surface shapes of the acoustic material influence the acoustical performance of the enclosure greatly. The experimental result shows that a larger noise reduction of about 23.75 dB(A) is achieved for the case of using pyramid shape PU foam. The 1/3 octave analysis is also carried out to study the effect of various shapes of acoustic material in the different frequency bands. The 1/3 octave analysis shows that wedge shape and pyramid shape acoustic materials have a better effect on the acoustic performance of enclosure in comparison to plane PU foam in the entire frequency region. The pyramid shape PU foam is very efficient in the high-frequency region between 2000 and 8000 Hz. Therefore, it can be concluded from the experimental results that the pyramid shape PU foam is very effective for improving the acoustic performance of the enclosure. The present experimental study demonstrates that the implementation of sound-absorbing material of different surface shapes would be an appropriate method for improving the acoustical performance of the enclosure.

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