



An Experimental Investigation on Acoustical Properties of Organic PU Foam Reinforced with Nanoparticles Fabricated by Hydrothermal Reduction Technique to Emerging Applications

Vinoth Kumar Selvaraj¹ · Jeyanthi Subramanian¹ · Manshu Gupta¹ ·
Mishelle Gayen¹ · Lenin Babu Mailan Chinnapandi²

Received: 7 June 2020 / Accepted: 9 October 2020 / Published online: 24 October 2020
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Abstract In this paper, synthesis of the bio-based eco-friendly PU foam using a mechanical stirrer mixing process and reinforcing with nanoparticles through absorption and hydrothermal reduction process is discussed. The acoustic shielding properties of the materials were tested using an impedance tube test setup. Identification of the functional groups and carbon compounds found in the different organic foams were done using the Fourier transformation infrared (FTIR) spectrum graph. The size, structure and homogenous distribution of the nanoparticles were observed through field emission scanning electron microscope (FESEM). These experiments were systematically designed by central composite design (CCD) and analyzed through response surface methodology (RSM) to learn the sound absorption coefficient of the material. The mathematical models developed to predict the optimum outcomes of sound absorption coefficient and noise reduction coefficient and experimental acoustic shielding properties were evaluated using impedance tube setup. The optimum weight percentage of multi-walled carbon nanotube (MWCNT), cupric oxide (CuO) and bamboo charcoal (BC) were 0.7%, 1.6% and 1.5%, respectively. The overall results point out that the nanoparticle reinforced with polyurethane foam could be considered as an outstanding material where it has been used in different fields like

defense and aerospace, where low weight and acoustic property are key requirements.

Keywords Organic foam · Nanoparticles · FTIR · FESEM · Central composite design · RSM

Abbreviation

NRC	Noise reduction coefficient
SAC	Sound absorption coefficient
MWCNTs	Multi-walled carbon nanotube
CuO	Cupric oxide
BC	Bamboo charcoal
FTIR	Fourier transform infrared
SEM	Scanning electron microscope
FESEM	Field emission scanning electron microscope
Wt.%	Weight percentage

Introduction

In current advancements in technology, noise is increasing in society due to construction, industrial, aerial/land transportation, and commercial activities, and is a major problem. Thus, decreasing the noise levels around us is of utter importance. Problems like loss of hearing and other auditory-related diseases, anxiety, stress, disturbance, sleeplessness and speech interruption are caused by noise [1–3]. Increased levels of noise and vibrations lead to structural failures by decreasing durability and serviceability and reduction in the life span of industrial equipment. For example, the vibrations due to flow instability in control valves occasionally defect the response to the control system which results in severe oscillations. From

✉ Jeyanthi Subramanian
jeyanthi.svite@gmail.com

¹ School of Mechanical Engineering, Vellore Institute of Technology, Chennai, Tamilnadu 600127, India

² School of Mechanical Engineering, Electric Vehicles Incubation and Testing Division, Vellore Institute of Technology, Chennai, Tamilnadu 600127, India

Table 1 Chemical composition for the fabrication of organic PU foam

Composition	Polyol	Isocyanate	Glycerin	Amine catalyst	Tin catalyst	Silicone surfactant	Physical blowing agent	Distilled water
Part by weight	100	85.38	3.5	1.5	0.25	1.5	8	7

Table 2 Details of reinforcement

Nanoparticles	Particle size	Density (g/cm ³)	Melting point (°C)
MWCNT	20–50 nm	1.7	3550
CuO	20–50 nm	6.31	1326
BC	20–50 nm	0.69	1200

the laws and regulations passed by the government to restrict noise in society, the necessity for noise reduction can be understood. Human activities are major contributors to noise or noise pollution [4]. Therefore, materials that are lightweight, flexible, thin, eco-friendly, low cost and have good sound absorption and reflection properties in the lower and wider frequency range are desired. At present, synthetic fibers are majorly used as acoustic shielding materials that are injurious to environment and human health [5]. Thus, a sustainable material is necessary, so for developing sustainability, castor oil-based organic polyurethane foam was used instead of harmful petroleum-based foam. Polyurethane was first developed in 1937 by Otto Bayer and is often described as ‘bridging the gap between rubber and plastic materials’. To manufacture polyurethane foam, the necessary materials are polyol and isocyanate [6]. Polyurethane is made of organic units bonded by urethane linkages. PU foam, in daily life, has a broad variety of uses due to its sole mechanical and physical properties, and good resistance of solvent that covers almost 29% of the material market, in furniture, construction building material, automobile and bedding [7, 8]. This makes PU foam a preferred choice for hybrid polymer composite for material matrix [9]. Polyurethane composites (PUC) have properties such as low density, high impact strength, abrasion resistance, high flexibility, damping ability, good weathering resistance, bio stability, high elongation at breaking point, anti-aging, weathering durability and low-temperature flexibility [10–16].

Polyurethane foams have some limitations, such as poor electrical conductivity, low thermal conductivity, poor tensile strength, high flammability and poor adhesion to metal surfaces [11, 12]. Compensation of disadvantages of PU foam composites has been done by reinforcing the foams with nanoparticles and natural fibers. For polymer matrix composites, filler materials like carbon nanotubes (CNTs) are an interesting choice due to their excellent

physical and chemical properties which permit the growth of high-efficiency composites [17]. Worldwide PU holds the sixth place for plastic sales, with a manufacture of 17 billion tons per year [18]. The mechanical properties of PU foam are enhanced by incorporating multi-walled carbon nanotubes (MWCNTs) in the foam up to 0.5 wt.% [19, 20]. The effects of the addition of MWCNTs to PU foam composites were investigated extensively by most researchers [21, 22]. Current studies indicate that the mixture of two different nanoparticles as fillers results in the fabrication of excellent properties due to synergistic effects among the fillers [12, 23, 24]. Rahmanianm et al. investigated the effect of hybrid fillers like MWCNT [25]. The self-assembling ability of nanoparticles is a major advantage of reinforcement in PU foam [26]. The role of MWCNT is to enhance the property at lesser concentration compared to traditional fillers is expected due to the tubular geometry of MWCNTs which offer large surface area along with higher aspect ratio. CuO nanoparticles are especially of interest due to its multifunctional properties and their high surface area may enhance bio reactivity and binding potential increase which enhances homogeneous nature throughout the composite matrix. Compared to regular charcoal, bamboo charcoal has ten times more surface area and is four times stronger in its absorption rate. The porous structure of bamboo charcoal provides countless tiny holes that effectively absorb odours, moisture, and polluted air particles such as formaldehyde, ammonia. Bamboo charcoal has a negative ionic charge attracting odours and excess moisture in the atmosphere and it can be recycled into the ecosystem [27–32]. From the literature [33–35], the sound absorption capability of the existing material in practice has been studied. In this paper, synthesis of the organic PU foam using a mechanical stirrer mixing process and reinforcing with nanoparticles through absorption and hydrothermal reduction process is discussed. The acoustic shielding properties of the material were tested using an impedance tube test setup. The morphology of the PU foam was observed by FESEM. To test the presence of a type of compounds in the PU foam, an FTIR test was conducted. The statistical analysis of NRC has been done to compare results with results of the experimental analysis of NRC. The motivation of our current work is fabrication of organic PU foam which can be used for a wide variety of applications ranging from sound insulation material for cars, building walls and

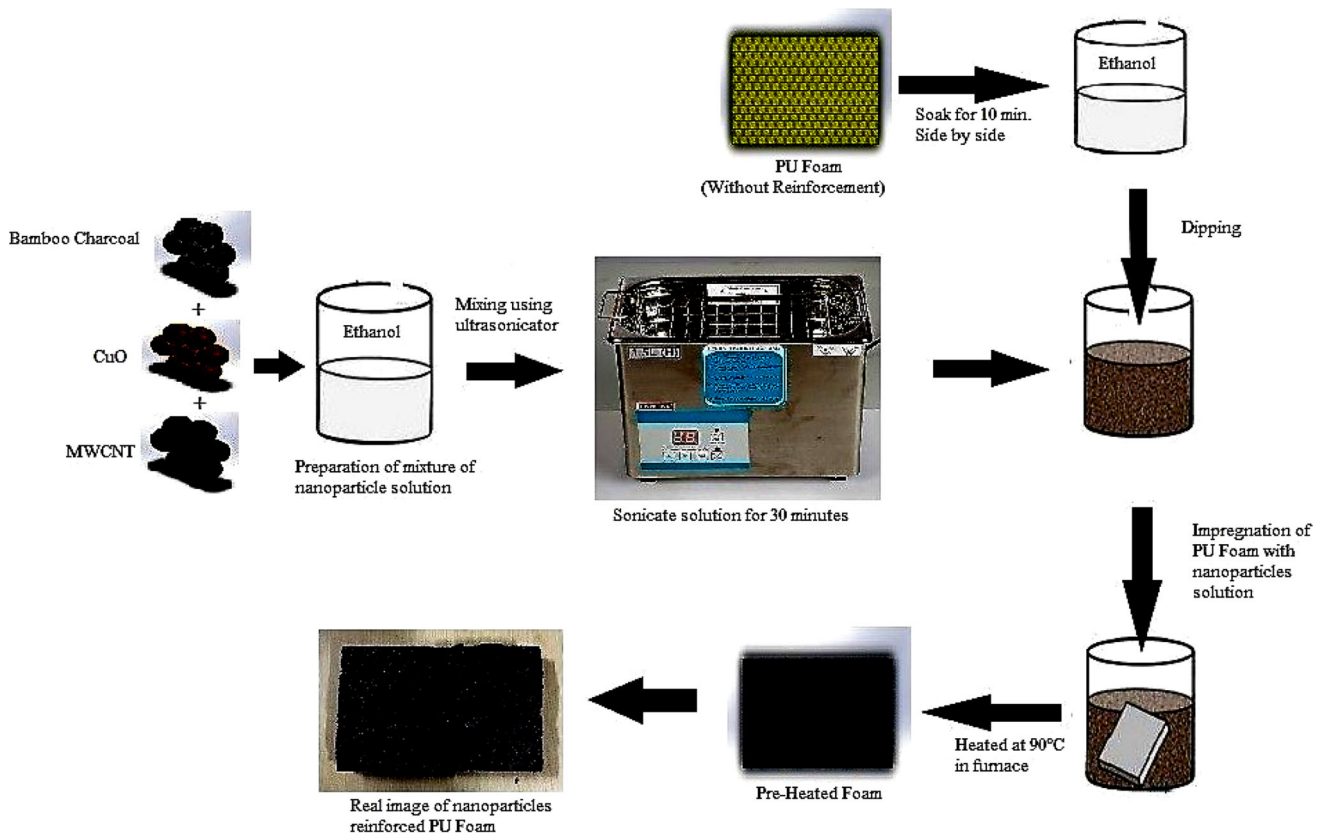


Fig. 1 Schematic diagram of fabrication of organic PU foam reinforced with nanoparticles



Fig. 2 Die setup coated with wax for fabricating organic PU foam

equipment causing noise to interior insulation of airplanes and space shuttles. Also, the manufacturing technique of fabricating the foam with mixture of three different nanoparticles reinforcement in one composite makes the

material one of its kind in the advanced composite materials. The production cost of the material is low, simple and consumes less time. The foam is less harmful to the environment as it is organic and the presence of bamboo charcoal increases its shelf life. Thus, the desired material is recommended for a vast range of applications.

Experimental

Materials and Characterization

In this study, chemicals specified in the Table 1 were purchased from Jagropol Industries, India to fabricate the polyurethane foam. Multi-walled carbon nanotube (MWCNT) and cupric oxide (CuO) with an average size of 20–50 nm were purchased from Sigma Aldrich, India with 99.5% purity. Table 2 provides the details of nanoparticles. The characterizations made in this research are FTIR and FESEM. Fourier transform infrared spectroscopy (FTIR) analysis of polyurethane nanocomposites was done using a FTIR spectrometer (IRaffinity 1, Shimadzu, Kyoto, Japan). The morphology of nanoparticles was examined by field emission scanning electron microscopy (FE-SEM; SUPRA 55, Carl Zeiss NTS GMBH, Germany).

Table 3 Physical properties of PU foam composites filled with various nano-reinforcements

Specimen	Weight of PU foam without reinforcement (g)	Weight of PU foam with reinforcement		Weight achieved after reinforcement (%)	Actual density (g/cm ³)
		Theoretical value (g)	Actual value (g)		
A1	12.00	23.90	19.60	82.00	0.068056
A2	11.95	21.05	17.20	81.71	0.059722
A3	12.00	21.80	17.80	81.65	0.061806
A4	12.00	21.80	18.10	83.02	0.062847
A5	12.10	19.10	16.30	85.34	0.056597
A6	12.00	18.30	16.00	87.43	0.055556
A7	11.98	21.08	16.88	80.07	0.058611
A8	12.00	22.20	18.16	81.80	0.063056
A9	12.00	20.80	17.90	86.05	0.062153
A10	12.05	24.35	21.10	86.65	0.073264
A11	12.00	18.70	16.96	90.69	0.058889
A12	12.00	24.30	20.80	85.59	0.072222
A13	11.91	18.61	16.25	87.31	0.056424
A14	12.00	21.50	18.36	85.39	0.063750
A15	12.02	21.52	18.36	85.31	0.063750
A16	12.02	21.52	18.36	85.31	0.063750
A17	12.02	21.52	18.36	85.31	0.063750
A18	12.02	21.52	18.36	85.31	0.063750
A19	12.02	21.52	18.36	85.31	0.063750
A20	12.02	21.52	18.36	85.31	0.063750

Nanocomposite Preparation

The flexible organic PU foam was prepared with a mixture of following chemicals mentioned in Table 1 by weight percentage. For developing sustainability, castor oil-based organic polyurethane foam was used instead of harmful petroleum-based foam and the schematic diagram of fabrication of PU foam reinforced with nanoparticles is mentioned in Fig. 1. The mixture was poured in a rectangular-moulded tray which was fabricated by aluminium material and inner surface of tray was coated with wax, in order to avoid the adhesion of foam in the aluminium mold as shown in Fig. 2. The polymerization reaction which occurs at room temperature between the two compounds liberates heat and carbon dioxide. The mixture was allowed to expand and then dried. The foam was taken out from the mould, and samples were prepared by cutting them according to the required dimensions – 120 mm × 120 mm × 20 mm.

The PU foam then went under the hydrothermal reduction process. It was first soaked in a container consisting of ethanol at room temperature. In another container, ethanol along with the required wt.% of cupric oxide, bamboo charcoal and multi-walled carbon nanotube for different

samples according to the experimental design as shown in Table 6 were taken and it was mixed using ultrasonicator bath for 30 min to avoid unsetting of the particle at bottom of the container. The foam was soaked in nanoparticle mixture for around half an hour side by side. This allowed the nanoparticles to distribute homogeneously throughout the solution and because of the self-assembling nature of nanoparticle, the solution was soaked homogeneously by the foam. The soaked foam was placed in the furnace for the evaporation of ethanol at 90 °C for around 1 h. The foam was taken out when it became dry and devoid of ethanol. All the samples were fabricated following the same procedure. From Table 3, we can conclude that there is a significant increase in the weight of the foam before and after the reinforcement with a minimum of 80% rise in weight according to different sample proportions and the actual density of all samples have been calculated. Thus, the required nanoparticle reinforcement was achieved during the fabrication of the sample.

Acoustic Experimental System

The acoustic experimental system consists of an impedance tube (900 mm length and 56 mm internal diameter), a

Fig. 3 Acoustic experimental system for testing sound absorption coefficient

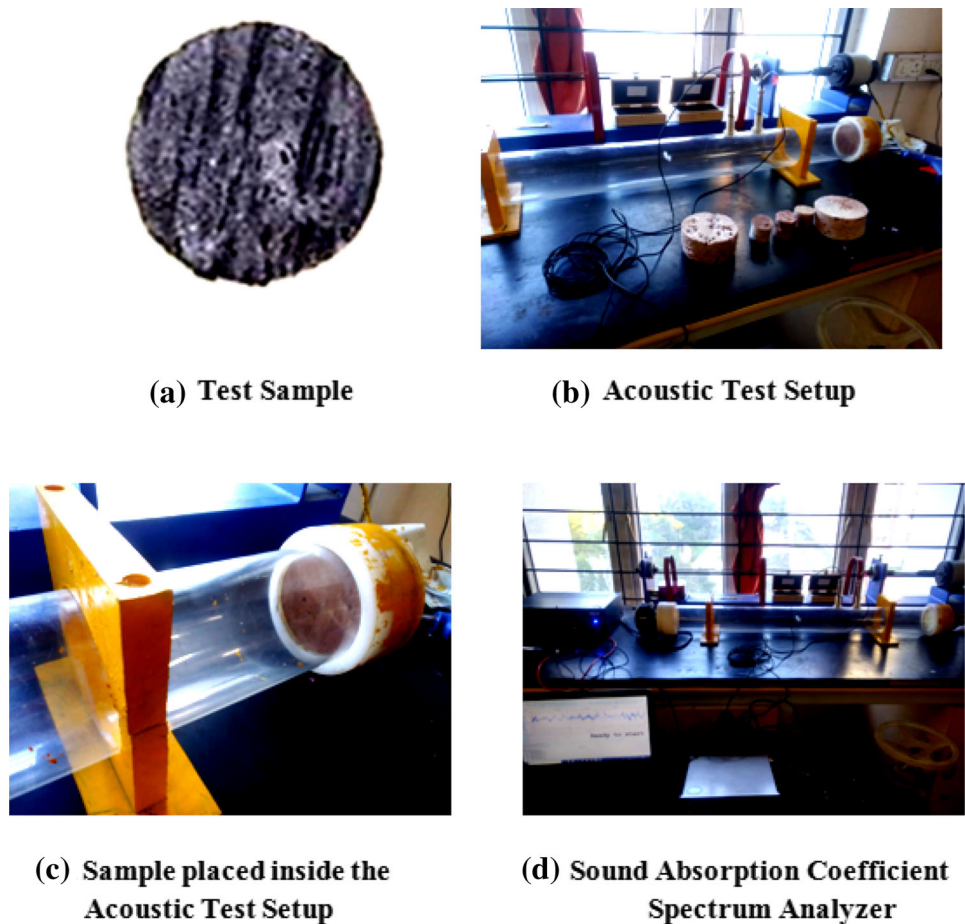


Table 4 Nanoparticles with their designations & corresponding levels

Nanoparticles (wt.%) with designations	Levels				
	- 2	-1	0	1	2
MWCNT (A)	0.25	0.5	0.75	1	1.25
CuO (B)	0.5	1	1.5	2	2.5
Bamboo charcoal (C)	0.5	1	1.5	2	2.5

speaker (20–2000 Hz frequency range), a pair of microphones, a personal computer with MATLAB software which controls the measurement automatically. The specimen of diameter 100 mm is cut out from the fabricated sample and was placed at right extreme end of the impedance tube; the speaker was placed in the left extreme end and the microphones were placed at the center of the impedance tube [33]. The controller was connected with the speaker and the microphones. By using the collected data, the sound absorption coefficient (SAC) of the specimen was calculated using MATLAB software. The diagrammatic representation of the acoustic experimental system is shown in Fig. 3.

Response Surface Methodology

The factors for the experiment are MWCNT, CuO and bamboo charcoal and the response is noise reduction coefficient (NRC). The designing (the composition of factors for each sample as shown in Table 6), analysis and calculations to determine results of reinforced PU foam was done using the central composite design (CCD) through response surface methodology in Minitab software. 20 samples (runs) which include 6 central points (A15–A20) as shown in Table 6 were chosen. The range of levels of the factors from low to high and their designations as shown in Table 4 were fed as input for the analysis. The

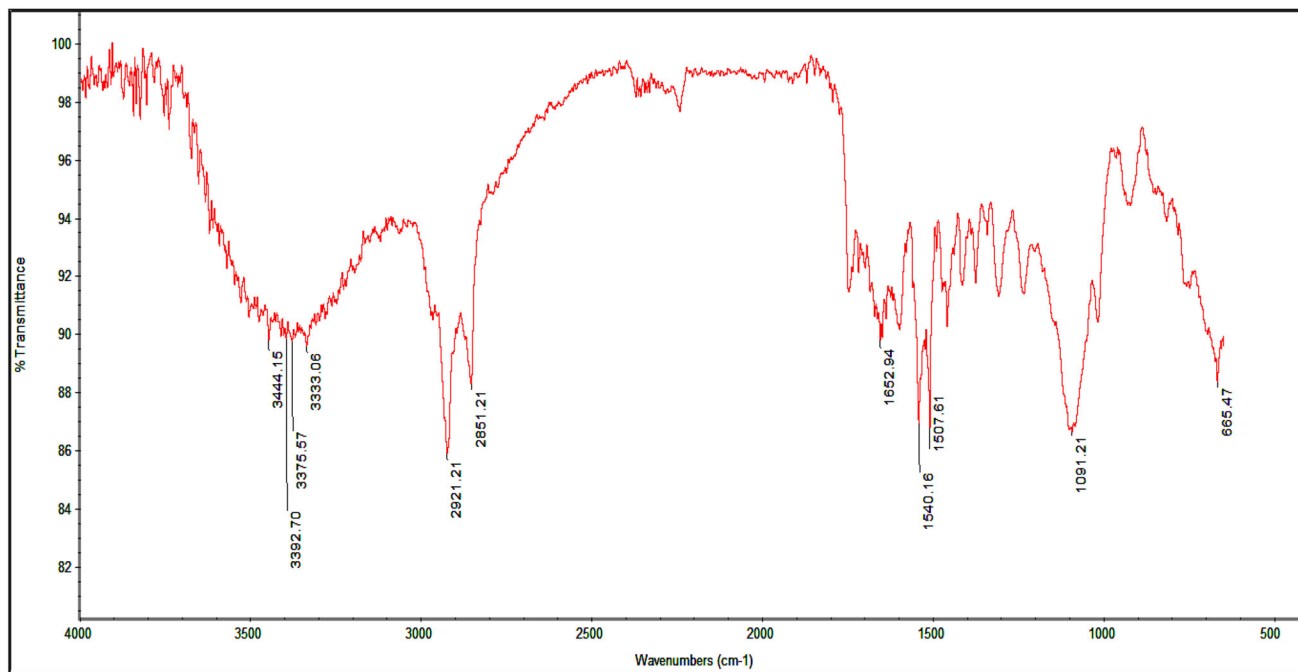


Fig. 4 Fourier transform infrared (FTIR) graph of non-reinforced organic PU foam

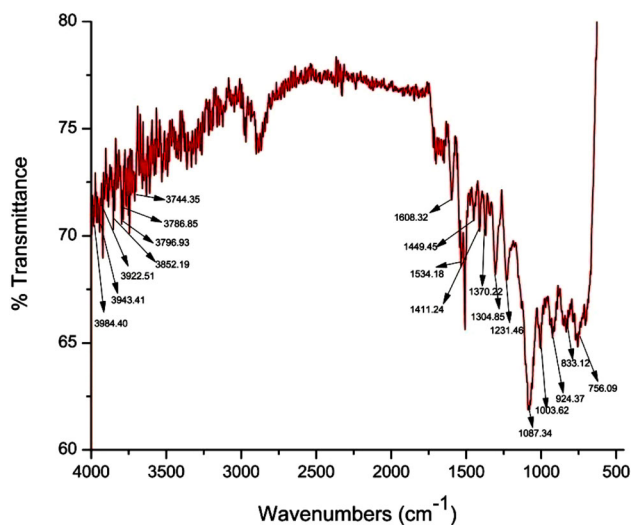


Fig. 5 Fourier transform infrared (FTIR) graph of nanoparticle-reinforced organic PU foam

foam was fabricated according to the experiment design in Table 6. Statistical analysis was done using analysis of variance (ANOVA).

For statistical acoustic analysis, the noise reduction coefficient (NRC) was obtained from the sound absorption coefficient by the following formula:

$$\text{NRC} = \frac{(\alpha_{250} + \alpha_{500} + \alpha_{1000} + \alpha_{2000})}{4} \quad (1)$$

α_{250} = Sound absorption coefficient at 250 Hz frequency.

α_{500} = Sound absorption coefficient at 500 Hz frequency.

α_{1000} = Sound absorption coefficient at 1000 Hz frequency.

α_{2000} = Sound absorption coefficient at 2000 Hz frequency.

$$\text{Error Percentage} = \frac{\text{NRC}_{\text{actual}} - \text{NRC}_{\text{predicted}}}{\text{NRC}_{\text{Actual}}} [\%] \quad (2)$$

$\text{NRC}_{\text{actual}}$ = Actual value of NRC obtained from experimental analysis.

$\text{NRC}_{\text{predicted}}$ = Predicted value of NRC obtained from regression equation from statistical analysis.

Results and Discussion

FTIR Characterization

Identification of the functional groups found in the different foams was done using the Fourier transformation infrared (FTIR) spectrum graph. In non-reinforced foam, around 3500 cm^{-1} the speaks are broad and this confirms the occurrence of $-\text{OH}$ functional group; the occurrence of $-\text{C}-\text{H}$ groups is confirmed in the range of 3000 cm^{-1} from the stretching of the peaks; the absorption around the range of $2165\text{--}2110 \text{ cm}^{-1}$ shows the occurrence of cyanide group and these can be seen clearly in Fig. 4 mentioned. While comparing Fig. 4 with Fig. 5, Fig. 5 clearly

Fig. 6 Comparison of sound absorption coefficient of samples with different proportions of reinforcement for high frequency

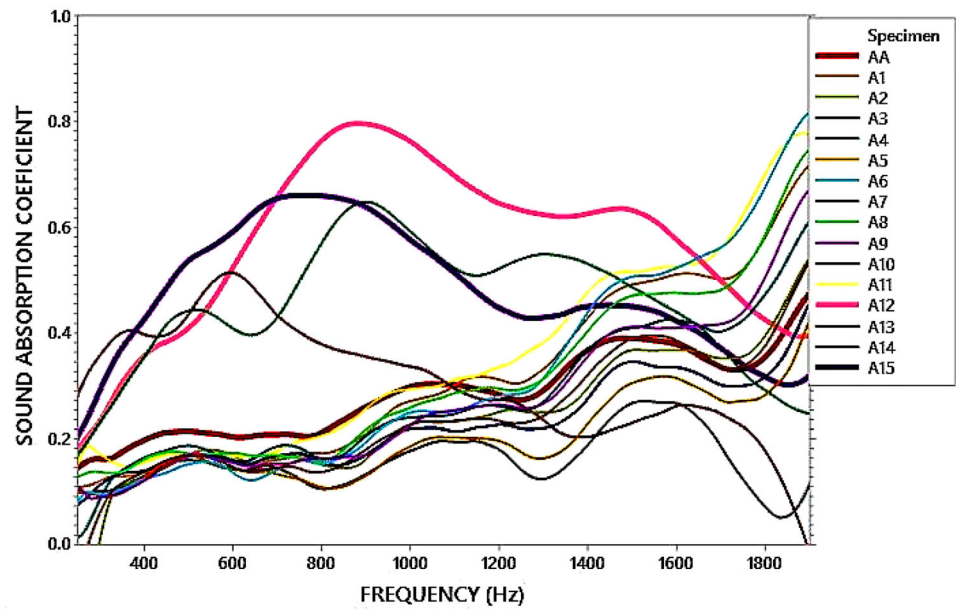
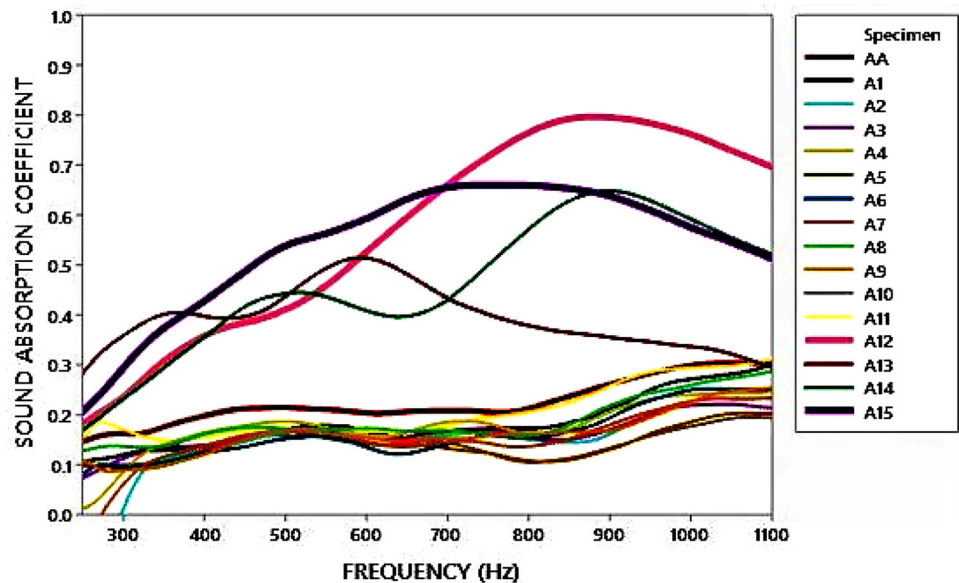


Fig. 7 Comparison of sound absorption coefficient of samples with different proportions of reinforcement for low frequency



indicates the addition of nanoparticles to the organic PU foam. The occurrence of sp^2 hybridized carbon is indicated by the peak in between the range of $1600\text{--}1700\text{ cm}^{-1}$. This is a characteristic of MWCNT because of the occurrence of carbon–carbon double bond ($C = C$). The reinforced PU foam has some deviations as shown in Fig. 5 due to good transmittance percentage from radiations. FTIR graph shows that the specimen has other nanoparticles along with the MWCNT. The collected data are unclear and a lot of noise can be found due to the occurrence of alkanes and alkynes with the mixture of different compounds, which indicates the presence of bamboo charcoal and multi-walled carbon nanotube in the composite.

Analysis of Acoustical Properties

From Fig. 6, it was concluded that specimen A12 has the highest peak around 0.8 of sound absorption coefficient (SAC) at around 870 Hz frequency which indicates that the sample A12 has the best acoustic shielding properties among all the samples for high-frequency range. And also from the experiments, it can be concluded that a minimum value of SAC, more than 0.6, was achieved in the high-frequency range of 700–1600 Hz. From Fig. 7, it was concluded that specimen A15 has the highest peak around 0.65 of sound absorption coefficient (SAC) at around 650 Hz frequency which indicates that the sample A15 has

Table 5 Experimental results of sound absorption coefficient (α)

Specimen	Sound absorption coefficient (α) corresponding to frequency (Hz)			
	250	500	1000	2000
AA	0.20	0.22	0.29	0.53
A1	0.27	0.14	0.29	0.68
A2	0.22	0.16	0.24	0.58
A3	0.18	0.17	0.21	0.56
A4	0.15	0.18	0.26	0.61
A5	0.16	0.17	0.23	0.56
A6	0.47	0.13	0.26	0.78
A7	0.14	0.17	0.19	0.54
A8	0.18	0.16	0.26	0.68
A9	0.34	0.19	0.27	0.62
A10	0.30	0.20	0.18	0.32
A11	0.20	0.18	0.27	0.63
A12	0.49	0.39	0.77	0.61
A13	0.50	0.42	0.32	0.40
A14	0.21	0.46	0.58	0.31
A15	0.16	0.53	0.58	0.53
A16	0.16	0.53	0.58	0.53
A17	0.16	0.53	0.58	0.53
A18	0.16	0.53	0.58	0.53
A19	0.16	0.53	0.58	0.53
A20	0.16	0.53	0.58	0.53

the best acoustic shielding properties among all the samples for low-frequency range. And also from the experiments, it can be concluded that a minimum value of SAC, more than 0.5 was achieved in the low-frequency range of 400–650 Hz. Both the samples with reinforcement had improved acoustic shielding properties than the normal PU foam without reinforcement, i.e., specimen AA as shown in Table 5. This indicates that MWCNT, CuO and bamboo charcoal imparted good and improved acoustic shielding properties. In Figs. 6, 7 specimen AA, A12 and A15 are highlighted. Table 6 shows that specimen A15 has the highest NRC value of 0.450, which shows it has the best acoustic shielding properties among all the samples.

Morphology of Nano-Reinforced Foam

Field emission scanning electron microscope (FESEM) was used for observing the accurate information on the morphology of nanoparticle-reinforced PU foam from 250 X to the maximum of 100 KX magnifications as shown in Fig. 8. Figure 8 (a) indicates the presence of open-cellular pores. Closed pore cellular structure indicates the occurrence of nanoparticles and that can be simply confirmed by Fig. 8 (b), while from images in Fig. 8 (c), uniformity due

Table 6 Noise reduction coefficient (NRC) value with RSM central composite experimental designs (L20)

Specimen	MWCNT (wt.%)	CuO (wt.%)	Bamboo charcoal (wt.%)	Noise reduction coefficient (dB)
AA	0	0	0	0.31
A1	1.00	2.0	2.0	0.210
A2	0.50	2.0	2.0	0.150
A3	0.50	2.0	1.0	0.280
A4	1.00	2.0	1.0	0.300
A5	1.00	1.0	2.0	0.200
A6	1.00	1.0	1.0	0.410
A7	0.50	1.0	1.0	0.260
A8	0.50	1.0	2.0	0.320
A9	1.25	1.5	1.5	0.185
A10	0.25	1.5	1.5	0.250
A11	0.75	2.5	1.5	0.320
A12	0.75	0.5	1.5	0.320
A13	0.75	1.5	2.5	0.210
A14	0.75	1.5	0.5	0.283
A15	0.75	1.5	1.5	0.450
A16	0.75	1.5	1.5	0.450
A17	0.75	1.5	1.5	0.450
A18	0.75	1.5	1.5	0.450
A19	0.75	1.5	1.5	0.450
A20	0.75	1.5	1.5	0.450

to self-assembling property of nanoparticle was observed throughout the sample and the monoclinic structure of cupric oxide can be seen in the figure and the porous structure of bamboo charcoal serves numerous tiny holes that efficiently absorb the nanoparticles. Figure 8 (d) clearly confirms the presence of multi-walled carbon nanotube (MWCNT), because MWCNT has 1D buckytube shape according to their high length-to-diameter ratio and it can be clearly seen in Fig. 8 (d).

Statistical Analysis

The design of experiments was based on response surface methodology of central composite design (CCD) using Minitab as shown in Table 6. The analysis and development of mathematical models for acoustic test with the input parameters and output responses from the RSM experimental design were carried out by the same software. A fit summary of the fit analysis found that for all the output responses a quadratic model was statistically significant. Hence, the same model was used in the current study. From Table 6, it can be inferred that sample A15 with 0.75 wt.% of MWCNT, 1.5 wt.% of CuO and 1.5 wt.% of bamboo charcoal has the maximum effect on noise

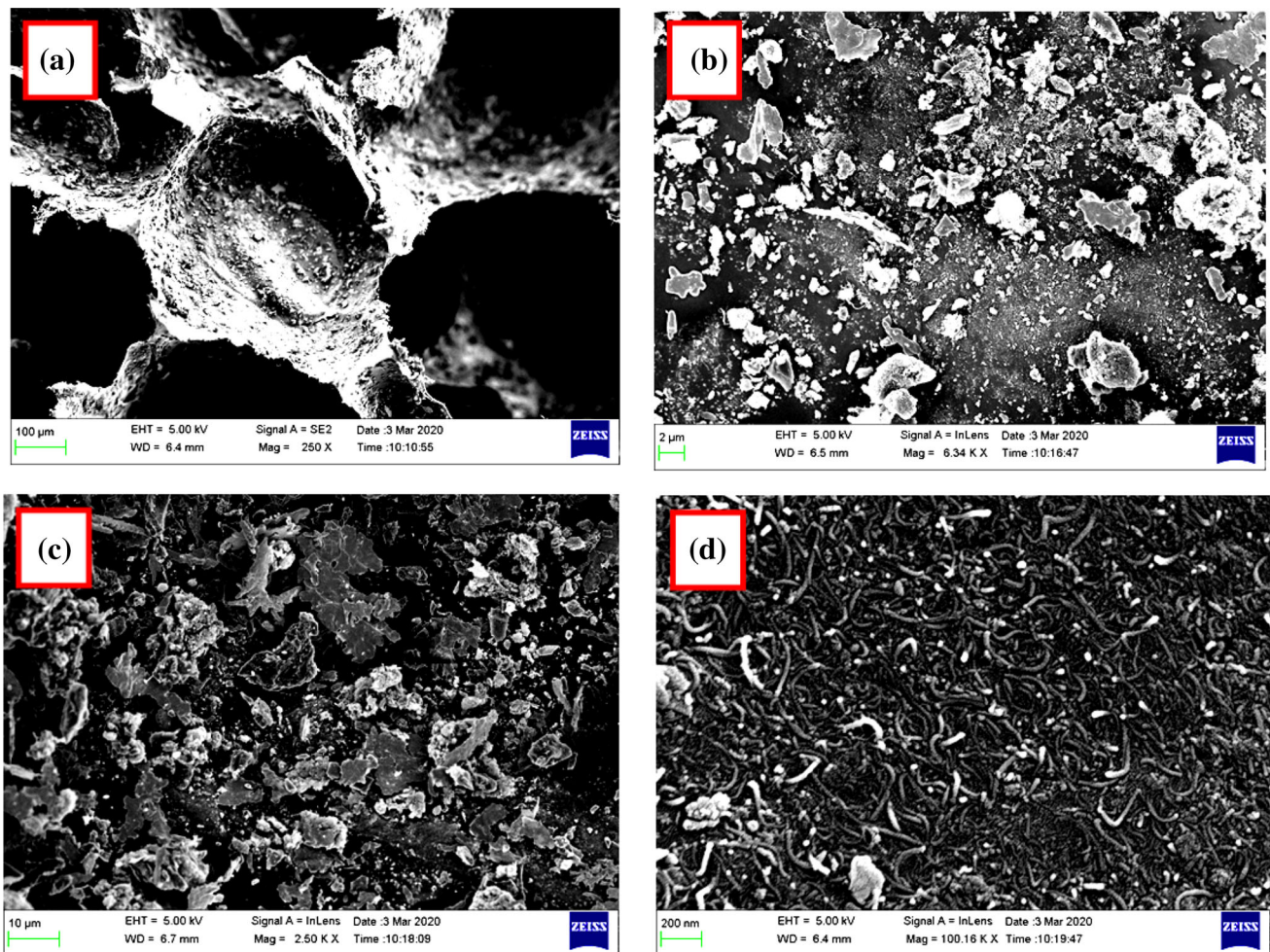


Fig. 8 Field emission scanning electron microscope (FESEM) characterization of nanoparticle-reinforced organic foam

reduction coefficient value of 0.450 and also from experiment analysis, it was concluded that specimen A15 is one of the best sample for low-frequency range. So, from this it can be concluded that the required quantity of wt.% of the given fillers impart good and desired acoustic shielding properties. Analysis of variance (ANOVA) was used to test the reliability of the model as shown in Table 7. It was observed from the F-value that all the results are significant and thus the model is statistically fit to the experimental results. Results indicate that the model can be used to forecast the results within a confidence level of 90%.

Table 8 indicates the actual and predicted results from the response surface methodology models for acoustic shielding using regression Eq. 3 as given below. From Table 8, it was observed that the maximum error percentage between the actual and RSM predicted NRC was below 5% which indicates that the regression Eq. 3 obtained from the analysis through RSM model is accurate, adequate and

a good fit; thus, it can be concluded that the actual and predicted results hold good agreement. The regression equation is,

$$\begin{aligned}
 \text{NRC} = & -1.3636 + 2.4954 \text{ CNT} + 0.4164 \text{ CuO} + 0.8137 \text{ BC} - 0.9369 \\
 & \text{CNT} * \text{CNT} - 0.13173 \text{ CuO} * \text{CuO} - 0.20523 \text{ BC} * \text{BC} - 0.2500 \\
 & \text{CNT} * \text{CuO} - 0.5300 \text{ CNT} * \text{BC} + 0.1150 \text{ CuO} * \text{BC}
 \end{aligned}
 \tag{3}$$

Figure 9 shows the main effects plot from which it was concluded that MWCNT and bamboo charcoal plays a major role in enhancing shielding effectiveness. Moreover, bamboo charcoal is added because of being organic in nature and its desirable property in being an excellent non-fungal agent, natural, fragrance-free, allergen-free and non-toxic powder. It’s natural adsorption characteristics coupled with its significant surface area makes it an effective adsorbent. From Fig. 10 (a), Fig. 10 (c), Fig. 11 (a) and Fig. 11 (c), it was concluded that increasing CNT

Table 7 Analysis of variance (ANOVA) for noise reduction coefficient (NRC)

Source	DF	Sum of squares	Mean square	F-Value
Model	9	0.189801	0.021089	247.17
Linear	3	0.114800	0.038267	448.50
A	1	0.103938	0.103938	1218.21
B	1	0.011579	0.011579	135.71
C	1	0.044206	0.044206	518.11
Square	3	0.130791	0.043597	510.98
A*A	1	0.086212	0.086212	1010.45
B*B	1	0.027268	0.027268	319.59
C*C	1	0.066186	0.066186	775.73
2-Way interaction	3	0.049537	0.016512	193.54
A*B	1	0.007813	0.007813	91.57
A*C	1	0.035112	0.035112	411.54
B*C	1	0.006613	0.006613	77.50
Error	10	0.000853	0.000085	
Lack-of-fit	5	0.000853	0.000171	
Pure error	5	0.000000	0.000000	
Total	19	0.190654		

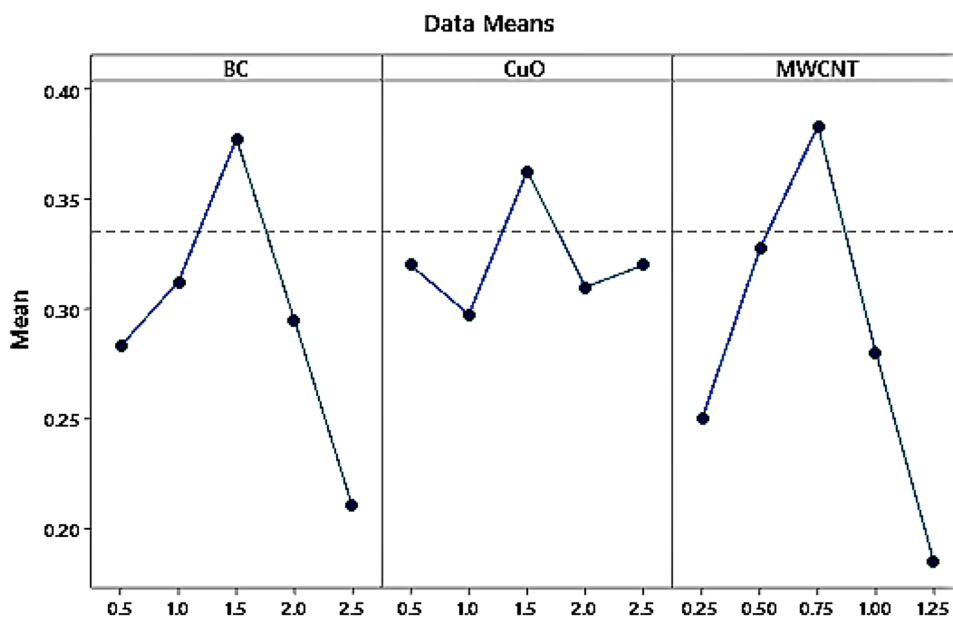
increases the NRC and also 0.9 wt.% of MWCNT, 0.5–1 wt.% of CuO and bamboo charcoal has an NRC value greater than 0.2. From Fig. 10 (b) and Fig. 11 (b), it was inferred that bamboo charcoal having 0.2 wt.% or greater and CuO with more than 1.5 wt.% has better sound absorption with NRC value above 0.2. Figure 12 shows a comparison between the actual and predicted NRC. It was observed that there is a linear regression relationship between the predicted and the actual values. This confirms

Table 8 Predicted value vs actual value for noise reduction coefficient (NRC)

Specimen	Actual value of NRC (dB)	Predicted value of NRC (dB)	Residual	Error %
A1	0.210	0.207260	0.00274	1.30476
A2	0.450	0.442235	0.00776	1.72556
A3	0.280	0.279225	0.00077	0.27679
A4	0.300	0.309250	- 0.00925	- 3.08333
A5	0.200	0.206050	- 0.00605	- 3.02500
A6	0.410	0.423040	- 0.01304	- 3.18049
A7	0.260	0.268015	- 0.00801	- 3.08269
A8	0.320	0.316025	0.00397	1.24219
A9	0.185	0.174984	0.01001	4.41419
A10	0.250	0.254934	- 0.00493	- 1.97350
A11	0.320	0.323664	- 0.00366	- 1.14492
A12	0.320	0.311244	0.00875	2.73633
A13	0.210	0.216964	- 0.00696	- 3.31607
A14	0.283	0.270944	0.01205	4.26016
A15	0.450	0.449184	0.00081	0.18139
A16	0.450	0.449184	0.00081	0.18139
A17	0.450	0.449184	0.00081	0.18139
A18	0.450	0.449184	0.00081	0.18139
A19	0.450	0.449184	0.00081	0.18139
A20	0.450	0.449184	0.00081	0.18139

the significance of the regression Eq. 3 obtained graphically from the RSM statistical model which is used to find the optimum range of different nanoparticles and in Fig. 12 most of the corresponding values lie on or near the regression line which proves the accuracy and adequacy of the model. From Table 9 and Fig. 13, it was concluded that

Fig. 9 Main effects plot for acoustic shielding properties



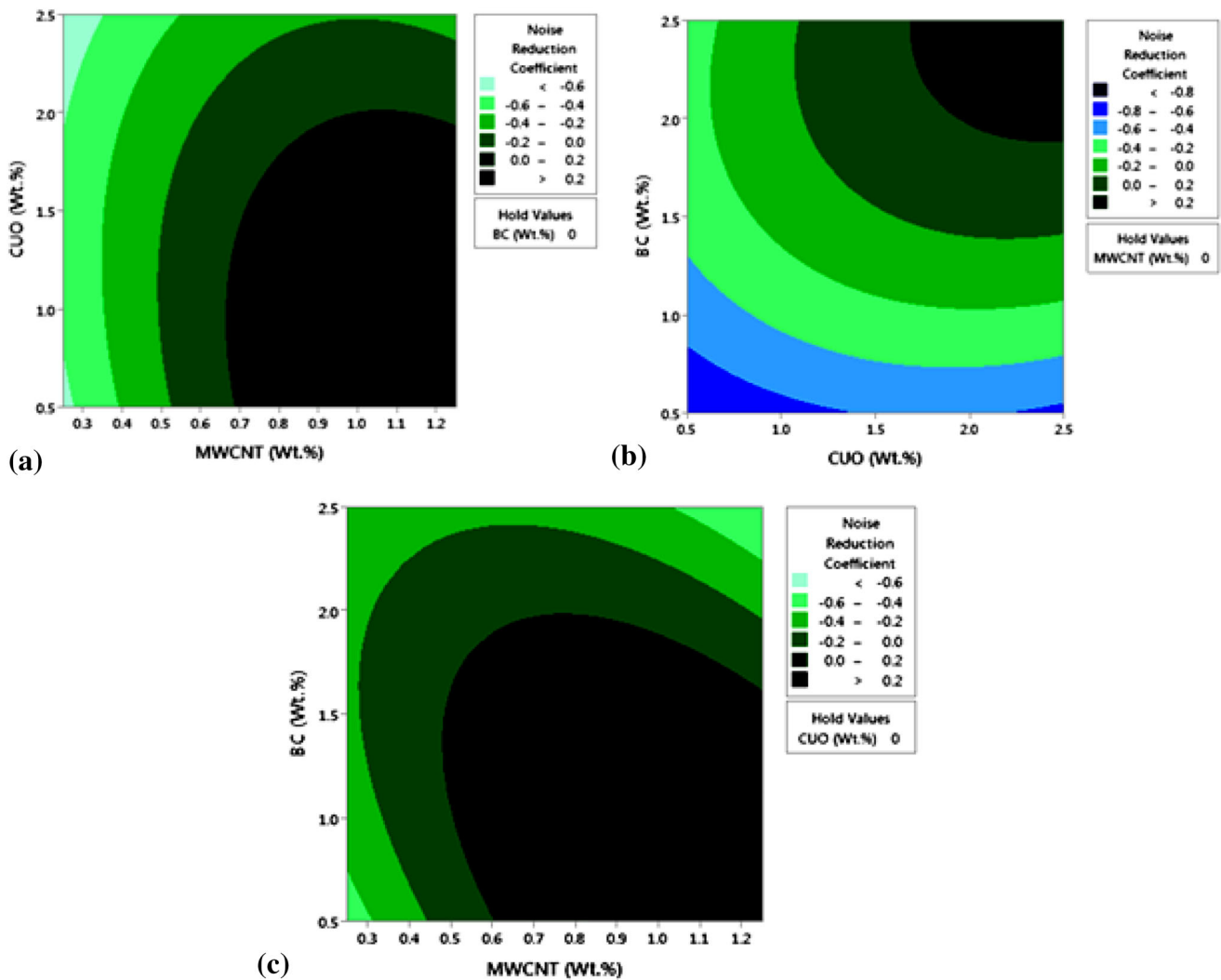


Fig. 10 Contour plots showing the effect of **a** MWCNT and CuO on NRC, **b** CuO and bamboo charcoal (BC) on NRC, **c** bamboo charcoal (BC) and MWCNT on NRC

the optimum range of weight percentage ratio of different factors for obtaining maximum NRC is 0.7 wt.% of MWCNT, 1.6 wt.% of CuO and 1.5 wt.% of bamboo charcoal, which gives maximum NRC value of 0.45 dB which falls under the desirable range of significance.

Conclusion

1. In this experiment, hydrothermal reduction technique was used to fabricate the polyurethane foam reinforced with nanoparticles with safe, reliable and precise control.
2. Ultrasonicator bath was used for a homogenous mixture of nanoparticles and the uniform mixture of nanoparticles is confirmed through field emission scanning electron microscope (FESEM).
3. Fourier transform infrared spectroscopy (FTIR) characterization verifies the occurrence of chemical composition in the sample. This verifies the nanoparticles substrate added in the sample.
4. From experimental analysis, the sample A12 with 0.75 wt.% of MWCNT, 0.5 wt.% of CuO and 1.5 wt.% of BC has an excellent SAC of 0.8 for high-frequency range of 870 Hz. And the sample A15 with 0.75 wt.% of MWCNT, 0.15 wt.% of CuO and 1.5 wt.% of BC

Fig. 11 3D Surface plots showing effect of **a** MWCNT and CuO on NRC, **b** CuO and bamboo charcoal (BC) on NRC, **c** bamboo charcoal (BC) and MWCNT on NRC

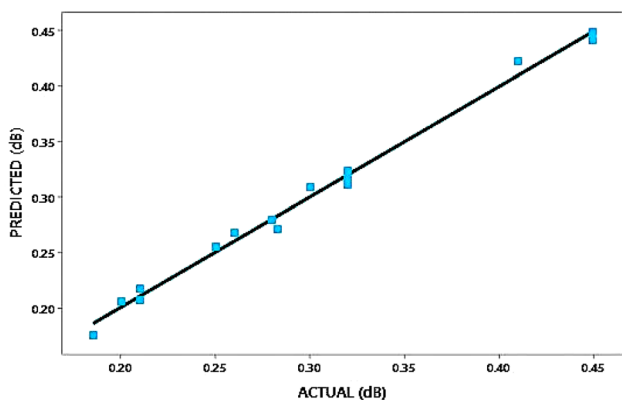
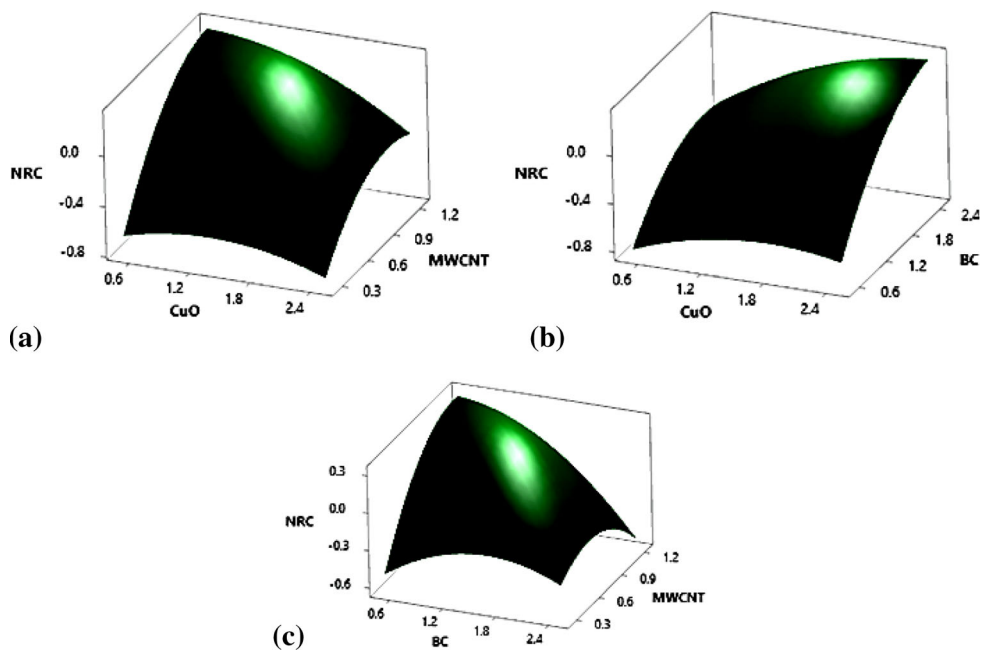


Fig. 12 Predicted vs. actual result of noise reduction coefficient (NRC)

Table 9 Optimum weight percentage of CNT, CuO and bamboo charcoal

Solution	MWCNT (wt.%)	CuO (wt.%)	Bamboo charcoal (wt.%)	NRC value FIT	Desirability
1	0.694444	1.57071	1.51010	0.451540	0.5

- has an highest peak of 0.65 for low-frequency range of 650 Hz and it has a noise reduction coefficient of 0.45.
- 5. Analysis of variance on each factors-CNT (wt.%), CuO (wt.%), and bamboo charcoal (wt.%) on NRC was investigated in detail using response surface methodology (RSM) statistical analysis. ANOVA showed significant results.
- 6. It is observed through confirmatory experiments and statistical analysis, that the error between predicted and actual values falls within 5%. Thus, the RSM model can be used to predict the acoustic properties of nanocomposite organic polyurethane foam. The optimum weight percentage of CNT, CuO and bamboo charcoal are 0.7, 1.6 and 1.5, respectively.
- 7. The nanocomposite organic polyurethane foam can be used as a sustainable alternative to traditional PU foams as it shows good and improved acoustic shielding properties. These kinds of foam are also low cost, flexible, lightweight and biodegradable. The PU foam can be used for biomedical equipment shielding which operates at low frequency, walls of automobile, layering in bodyworks of spacecraft's.

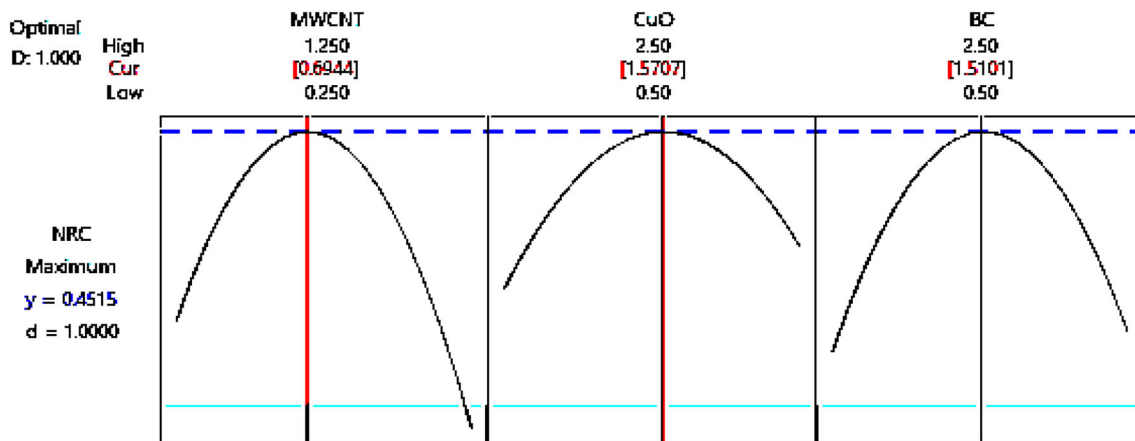


Fig. 13 Optimization curve of factors for acoustic shielding properties

Acknowledgement We are grateful to VIT-CHENNAI for providing us with the Seed Fund and fully operational laboratory for carrying out the experiments. We are also thankful to research scholar Mr. Yuvaraj L, Vellore Institute of Technology, Chennai for serving and providing us with basics and knowledge for the study of the results and material development and Mr. Murugesun GK, Senior Lecturer, District Institute of Education and Training, Thoothukudi for the support of enrichment of the article.

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