Sound absorption, Thermal and Mechanical behavior of Polyurethane foam modified with Nano silica, Nano clay and Crumb rubber fillers

R.Gayathri, R.Vasanthakumari, C.Padmanabhan

ABSTRACT

Lot of research is going on in developing materials suitable for absorbing sound and reducing noise. By virtue of their superior vibration damping capability and attractive characteristics such as visco elasticity, simple processing and commercial availability polyurethane foams are extensively applied not only in automotive seats but also in various acoustical parts. However, the sound absorption coefficient of polyurethane foams is high (0.8 – 1.0) in high frequencies ranging from 300 to 10000Hz while it is found to be low (0 to 0.5) at low frequencies (10 to 200 Hz).

In this study new polyurethane based porous composites were synthesized by in situ foam rising polymerization of polyol and diisocyanate in the presence of fillers such as nano silica, crumb rubber and nano clay. The effect of these fillers at various concentrations up to 2% was studied on sound absorption characteristics, thermal stability, and mechanical properties. Sound absorption coefficient was determined using standing wave sound impedance tube method. The sound absorption coefficient of filled PU foams is found to be increasing from 0.5 to 0.8 with increasing frequency from 100 to 200 Hz at higher content of the fillers employed. In addition to enhanced sound absorption properties in low frequency region, the composite foams exhibit superior thermal and mechanical properties. Further foam cell structure and size determined by using SEM and its effect on various properties will also be highlighted.

Index Terms - crumb rubber, low frequency sound, nano clay, nano silica, Polyurethane foam, Sound absorption coefficient.

1. INTRODUCTION

Now a day the noise pollution has become a serious issue, the demand for a better environment and more diversified life styles is increased. Therefore thin, light weight and low-cost composite materials that will absorb sound waves in wider frequency range are strongly desired. Polymeric foams have been widely used as sound absorbing materials and sound energy of incident sound wave falling on the material is partially dissipated as heat due to air friction inside polymeric cells and viscous friction between adjacent polymer chains [1].

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Flexible polyurethane (PU) foams have been extensively used for absorbing sound and reducing noise, whose attractive characteristics include its excellent visco elasticity, relative simple processing, light weight and commercial availability. They are used as seating, cushioning and sound absorbing material in automobile industry and as sound absorbers in compressors, pumps, boilers, electrical installations etc [1].

Generally the sound absorption capacity of PU is strong in high-frequency regions but relatively weak in low-frequency because of the low capacity of sound energy attenuation [2]. The sound absorption ability of polymeric foams is critical especially for the low-frequency noise. Materials with greater thickness are needed to achieve good sound absorption at lower frequency region. A large portion of the structural-borne noise occurs in low frequency in the range of 30-500 Hz while air-borne noise is mostly contained in medium and high frequency ranges of 500-8000 Hz [3]. Possible sources of low frequency noise are many and varied but are often industry related such as pumps, compressors,

generators etc. Apart from PU foam system there are other lot of systems and fillers were studied for sound absorption. Mendelssohn et al [4] studied the hollow porous microspheres of polystyrene dispersed randomly in PU, and the obtained material has many properties, including high porosity, high compression strength, low acoustic reflectivity, and relative intensity to the changes of the frequency. Cushman et al [5, 6 and 7] found that the mixtures of high and low characteristic acoustic impedance fillers loaded in the polymer can reduce the noise generated by sound, vibration, and shock, and the obtained material has excellent sound absorption properties. Verdejo et al[8] found that low loading fraction of carbon nanotubes (CNT's) in flexible polyurethane foams have relatively high effect in sound absorption; even 0.1% CNT's can enhance the acoustic absorption dramatically, which leads the peak absorption coefficient to increase up to 90% from 70% for the pure polymer foam especially in the high frequency region. Recent researches on recycled rubber particles from tyre known as crumb rubber shows that crumb rubber can be employed as filler for noise absorption study [9 - 11]. Jamaluddin N et al showed that multi-layer coconut coir fibres with airspace layers increase the absorption coefficient of the material at lower frequencies [12]. Sezgin Ersoy et al suggested that the backing of industrial tea-leaf-fibre with a single layer of cotton cloth increases its sound absorption properties significantly [13]. Yang HS et al showed that Composite boards of random cut rice straws and wood particles, were found to demonstrate higher sound absorption coefficient than particleboard, fiberboard and plywood [14]. In order to get many desired properties in single system nano composites has been adapted widely. Acoustic properties of PU foams are usually improved by incorporation of micro-sized fillers because higher density and better morphology can be achieved but high amounts of micro fillers can lead to increase in weight of foam and reduced sound absorption efficiency. Hence studies were carried out with nano materials which can lead to significant improvements in sound absorption without much negative effects, especially in weight increasing [15, 16].

The present research work deals with the preparation and properties of flexible PU foam filled with three different fillers namely Nano Silica (NS), Crumb Rubber (CR) and Nano Clay (NC) at different composition to study their effect on sound absorption at low frequency range. The effect of these fillers on thermal and mechanical properties is also highlighted.

2. EXPERIMENTAL

2.1 Materials

The commercial raw materials of PU foam, including Part A (the mixture of polyether polyol, catalyst, blowing agent and surfactant) and Part B (isocyanate based on mixture of TDI and MDI), were supplied by Manali Petrochemicals ltd, Chennai. Nanosilica with trade name Cab-o-sil was supplied by Cabot Corporation, Chennai. 40 mesh size crumb rubber was supplied by RK Polymers, Chennai and Nano clay (Organically modified Montmorillonite clay ,OMMT) with trade name Nanofil 5 was supplied by Sud Chemie, Germany. Following literature studies and considering the limitations in the preparation of the isocyanate mixture with fillers [2] the following quantities of fillers were used in this study 0.35%, 0.70%, 1.4% and 2.0% .

2.2 Method

The PU foams with and without varied content of fillers were prepared by the free rising foaming method. The desired amount (0 - 2%) of each filler was mixed with isocyanate (Part B) using a magnetic stirrer for 30 min. Then, Part A was added (with mass ratio of 100:38 for Part A and Part B) and stirred with a mechanical stirrer at 1500 rpm for 15 Sec. The mixture was then poured rapidly into an open cylindrical mould of dimension 100mm dia before foaming starts. It was allowed to cure at room temperature for 12 hours and then demolded.

2.2.1 Physical and Mechanical measurements

Foam density measurements were carried out as per IS 7888-1976 standard. Average of 5 values of density was considered for each sample. Universal Testing Machine (UTM, DAK Series 9000) was used to determine the tensile strength and elongation at break of all samples at room temperature as per IS 7888-1976 standard.

The cross head speed was kept as 500mm/min. Uniaxial compression tests were carried out in UTM, DAK Series 9000 according to EN ISO 3386-1 standard. All the compression test measurements were performed at a crosshead speed of 100mm/min.

2.2.2 Microscopic studies

The surface micro structure was observed using S-3400 Scanning Electron Microscope (SEM) for pure and filled PU samples after vacuum sputter coating with gold.

2.2.3 Thermo gravimetric analysis (TGA)

TGA studies were carried out using SII Nanotechnology instrument TG / DTA 6200 with ~ 10 mg sample up to 800 ^{o}C at a heating rate of 20 ^{o}C / min in nitrogen atmosphere.

2.2.4 Sound Absorption Coefficient measurement

The sound absorption test was carried out at IIT Madras using Standing Wave Apparatus. The acoustic test system comprises of an impedance tube, microphone, loud speaker and digital frequency analyzer as shown in Fig.1. The absorption coefficient was calculated as the average value of three cylindrical foam pieces of dimension 90mm in diameter and 15 mm thick, for different frequencies in the range from 100 to 200 Hz. Sound absorption coefficient(α) can be defined as the ratio of energy absorbed by a material to the energy incident upon its surface.

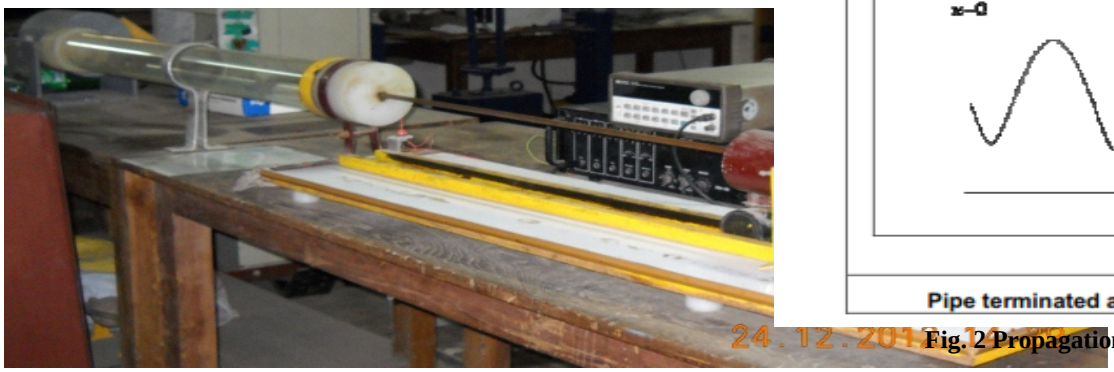


Fig.1 Standing wave apparatus

Theory

Assuming that a pipe of cross-sectional area S and length L is driven by a piston at x=0. If the piston vibrates harmonically at a frequency sufficiently low that only plane waves propagate.(Fig. 2) For a circular waveguide (pipe) filled with air, the highest frequency at which only plane waves will propagate is given by fmax =100/ a where 'a' is the radius of the waveguide. When the pipe is terminated with acoustic absorbing material, some of the incident sound energy is absorbed by the material and the reflected waves do not have the same amplitude as incident waves. In addition the absorbing material introduces a phase shift upon reflection. The amplitude at a pressure anti-node (maximum pressure) is A+B, and the amplitude at a pressure node (minimum pressure) is A-B. It is not possible to measure A or B directly. However, the amplitude at a pressure node and anti-node can be measured using a microphone probe which is set in a standing wave tube. We define the ratio of pressure maximum to pressure minimum as the standing wave ratio (SWR).

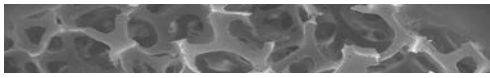
Thus **SWR** = (A + B) / (A - B) where A+B is Pressure maximum, A-B is pressure minimum.

The reflection coefficient R is defined by

$R = B / A, = (SWR + 1) / (SWR - 1)$

and finally the Sound absorption coefficient

$\alpha = 1 - R^2 = 1 - (SWR - 1)^2 / (SWR + 1)^2$



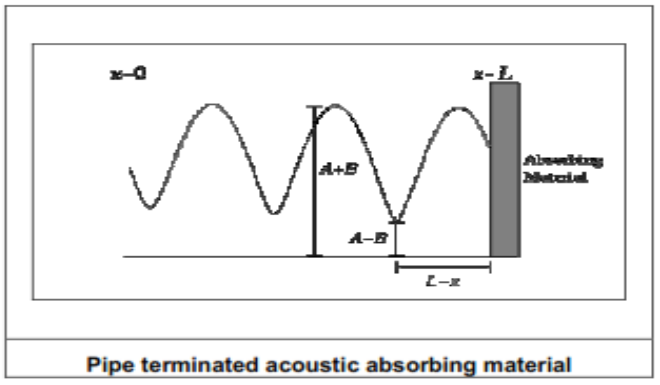


Fig. 2 Propagation of sound waves

3.0 RESULTS AND DISCUSSION

3.1 Foam density and Microstructure:

The densities of the filled foams (Fig.3) are higher than that of the pure polymer foam. This may be due to high content of fillers which would fill up more voids thus increasing the density.

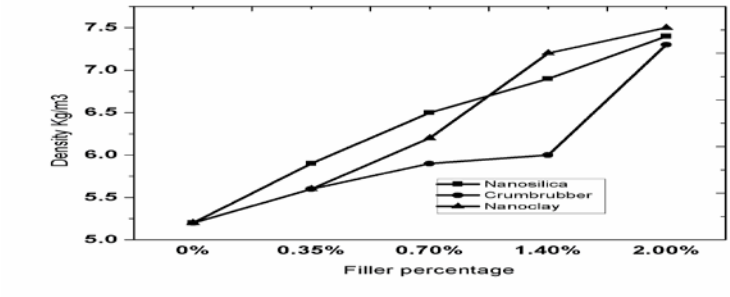


Fig. 3 Effect of fillers on density

Microstructure of the PU samples was determined using SEM and Fig 4 (a) to (d) show the SEM images of pure PU foam and filled PU foam with 1.4 % nano silica, 1.4% crumb rubber and 1.4% nanoclay respectively.

S. No	Properties	Pure foam	Nano silica	Crumb rubber	Nano clay
1	Mean cell size (µm)	269	274	278	272.3
2	Mean cell wall thickness (µm)	91.95	97.6	102.15	93.5

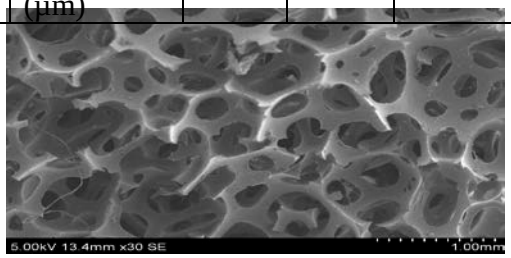


Fig. 4a Pure foam

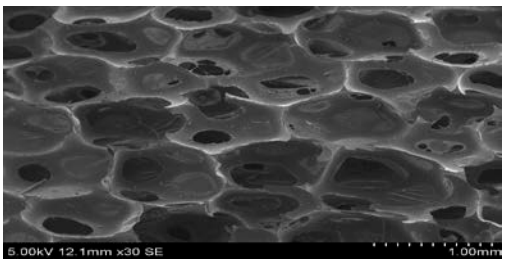


Fig. 4b 1.4%Nano silica in PU foam

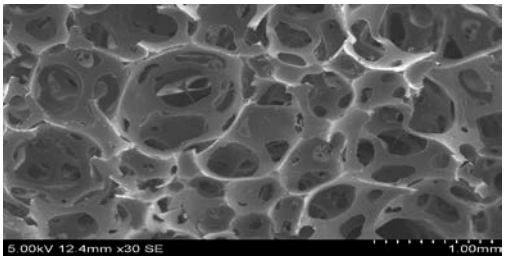


Fig. 4c 1.4% Crumb rubber in PU foam

Fig. 4d 1.4% Nano clay in PU foam

Cell edges and cell walls are distinctly visible with almost uniform cell structures throughout in all the compositions of PU foams. Close inspection of polymer matrix reveals a good dispersion of the fillers thorough out the sample, in both the walls and particularly the strut of cellular structure [8].

Table 1 Mean cell size and mean cell wall thickness of pure foam and 1.4 % filled PU foams.

SEM results are further analysed for cell dimensions and the results are shown in Table 1. Both cell size and cell wall thickness of filled foams are higher than that of pure foam. Increase in cell size may be attributed to increased gas diffusion. One hypothesis is that diffusion is enhanced at the polymer/filler interface due to poor interaction and increased free volume in the polymer [8].

3.2 Thermal Stability

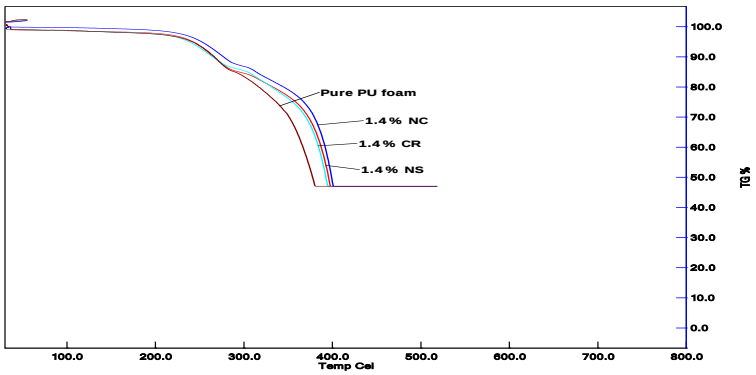
One of the draw backs of PU foam is its poor thermal stability. So TGA was performed to assess the effect of the addition of nano silica, crumb rubber and nano clay fillers on the thermal stability of the flexible polyurethane foam.

Fig. 5 TGA thermo grams PU foam with and without 1.4% filler

Fig. 5 shows the thermo grams of the foam samples.

Table 2 summaries the results of thermal stability at 50% decomposition of the samples obtained from the TGA thermo grams. The temperature of 50% mass loss corresponds to the temperature range of the decomposition of hard segments. The value of this temperature increased with the presence of each investigated filler [17]. The maximum increase was observed at 1.4% loading levels of NS, CR and NC (Fig.5). The residual mass remaining at 600^{o}C is 8.8% for pure PU foam, 9.3% for NS / PU foam, 5.4% for CR / PU foam and 11.9% for NC / PU foam.

Table2 Thermal stability of pure and filled foams



3.3 Mechanical properties

The effect of fillers on tensile properties of PU foam is shown in Fig 6a and 6b. As expected, there is a gradual increase in tensile strength and decrease in elongation at break with increase in filler content for all the three fillers. The increase in cell wall thickness with the addition of fillers makes the cell wall stiff and results in a reinforcing effect on PU foam [3].

Filler percent	Nano silica	Crumb rubber	Nano clay
0%	378.2	378.2	378.2
0.35%	378.6	380.9	390.3
0.70%	392.6	387.9	393.0
1.4%	396.4	393.4	399.6
2.0%	395.3	390.5	394.0

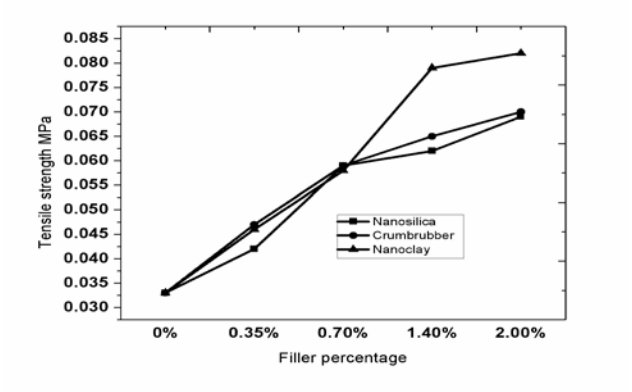


Fig.6a

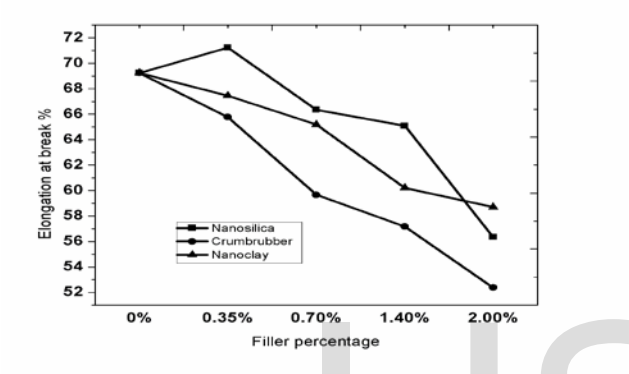


Fig. 6b

Effect of fillers on tensile strength (6a) and elongation at break (6b)

Compression strength of the samples was measured at 50% deflection and the compression strength values show an increasing trend with the increase in filler content (Fig.7). It is assumed that the fillers, as an additional physical cross linker, increased the modulus of flexible segment in the polyurethane matrix resulting in increased compression strength [18]. Compression strength shows a maximum value at 1.4% loading followed by decrease at 2.0%. Higher amounts of fillers beyond 1.4% make the cell wall brittle, resulting in decreased compression strength.

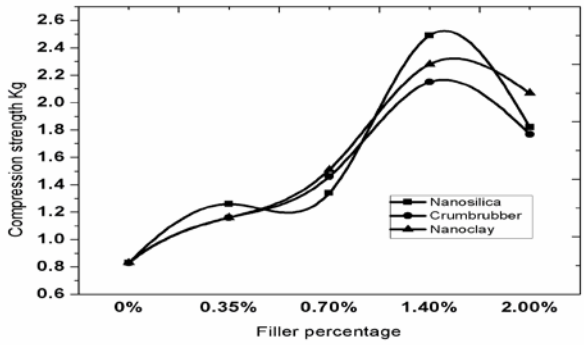


Fig. 7

Effect of fillers on compressive strength (Fig.7)

3.4 Sound absorption of pure and filled flexible polyurethane foams

PU samples with 0.35%, 0.70%, 1.4% and 2.0% of NS, CR and NC were tested at the frequency ranging from 100 to 200 Hz in the experiment. Fig 8a, 8b and 8c show the experimental results for the acoustic absorption coefficient of the samples, as a function of frequency.

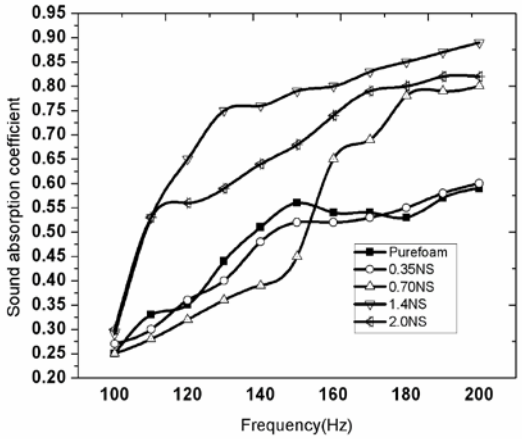
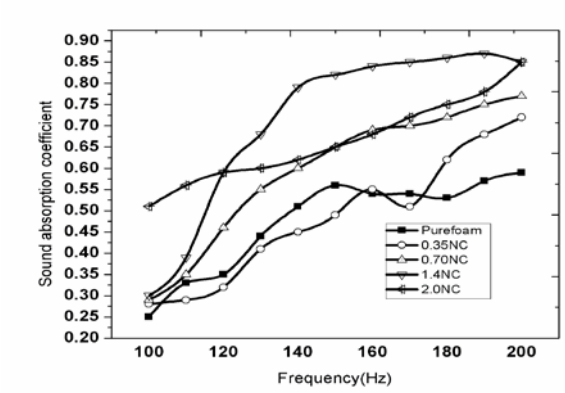


Fig. 8a PU foam with NS



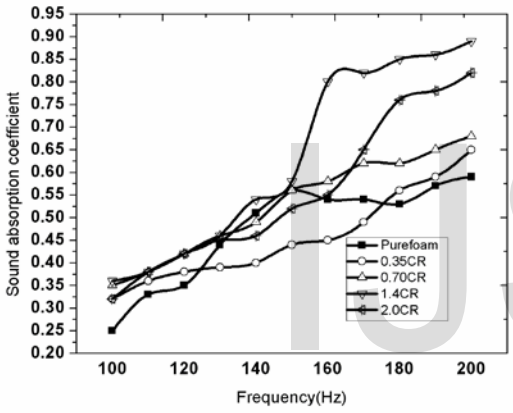


Fig. 8b PU foam with CR

Fig. 8c PU foam with NC

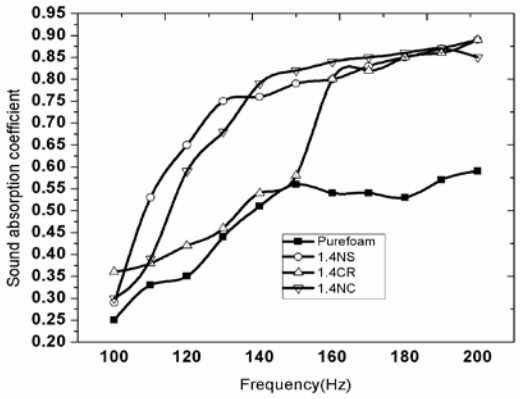


Fig. 8d PU with 1.4% NS, CR and NC

From these figures it is clear that absorption coefficient increases with increase in filler content and with increase in frequency. Pure foam shows an increase in the absorption coefficient only up to 52% in the frequency range 100 – 200 Hz. On the other hand the addition of various fillers shows an increase up to 80%. All the three fillers at loading level of 1.4 % show superior sound absorption capacity at low frequency region of 100-200Hz. It is also found that for the filler content of 1.4% of NS, CR and NC sound absorption is the highest (Fig. 8d).The increase in acoustic effect may be due to the large surface area of fillers at the PU-filler interface where the acoustic energy can be dissipated as heat energy [8]. Further in case of porous sound absorbers sound propagation takes place in a network of interconnected pores such that viscous and thermal interaction causes the acoustic energy to be dissipated and convert them into heat energy. At low frequencies porous PU foams absorbs sound by energy loss caused by heat exchange. This is an isothermal process. The absorbed acoustic energy moves inside the cells by the friction with air. This friction is changed into heat. Formation of fine morphology by fillers creates more paths for passing sound waves into foam structure and thus, they absorb more sound.

4.0. CONCLUSION

Filled PU foam composites with different loading levels (0.35%, 0.70%, 1.4% and 2.0%) of nano silica, crumb rubber and nanoclay were prepared by free rising foaming method. Increase in filler content affected the foaming process and cellular structure of foam as studied from SEM pictures. Maximum sound absorption coefficient of 80% and improved thermal properties were obtained at 1.4% weight concentration of all the three fillers. Mechanical properties also show a significant improvement with the addition of fillers. It is interesting to find that foam thickness of 15mm is sufficient to result in improvement in acoustic properties with fillers. Thus, from the above studies one can conclude that flexible PU foam with 1.4% weight concentration of nano silica, crumb rubber or nano clay can improve the acoustic property in lower frequency range 100-200Hz in addition to enhancement in thermal and mechanical properties. Further studies are in progress to determine optimum thickness of the foam for best sound absorption coefficient in the low frequency range.

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