International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8 Issue-3, September 2019

Synthesis and Evaluation of Polyurethane Foam Composites for Enhanced Sound Absorption at Low Frequency

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Abstract: Polyurethane foams are extensively used as sound absorbing materials in various automobile parts. However, the sound absorption capability of polyurethane foam ispoorin low frequency range. The advancement of technologies to develop newerpolymer composites, provide scope to develop composite polyurethane foam with better sound absorption coefficient in low frequency range. Composite foams are made with two different filler materials as crumb rubber and coconut fiber, in varying weight fraction of up to 2.0%. Density, Sound absorption coefficient, and Noise reduction, measurements were done on all polyurethane foams. The effect offiller additionsto polyurethane foams ondensity and sound absorption coefficient at low frequency are discussed.The 1.4 % crumb rubber polyurethane foam offers the best combination of low density, improved sound absorption coefficient value and noise absorption at low frequency.

Index Terms— Polumer Composites; Crumb Rubber; Coconut Coir; Sound absorption; Noise Reduction; Impedance tube.

I. INTRODUCTION

The Polyurethane foams are extensively used as sound absorbing materials in various automobile parts owing to their light weight, ease of production, and excellent sound absorption characteristics [1]. However, a large portion of the noise contributed by the structural members of automobiles is within the low frequency sound range, where the sound absorption capabilities of conventional polyurethane foam are inadequate [2]. The advancement in technologies to develop newer polymer composites, provide the scope to develop composite polyurethane foam with better sound absorption coefficient with low frequency sound range. Coconut coir has found its application in the development of composites for automobiles, owing to its lesser bulk density, natural availability and biodegradable nature [3-5].

Manuscript published on 30 September 2019

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In recent times, Coconut coir has gained attention as an alternate material in manufacturing of composites with sound absorption capabilities [6]. Crumb rubber derived from granulizing the recycled automobile tyres; possess excellent elastic properties coupled with durability. Crumb rubber addition to composites tends to improve the sound absorption capabilities [7].

The use of scrapped tyres which pose a threat to environment and coconut coir an abundant natural waste, as fillers for composites will result in more sustainable and less expensive materials [8]. Mamtaz et al, investigated the acoustic absorption capability of coconut coir fiber and rice husk composite and reported an efficiency level of 80 % – 90 % [6]. Yang et al., reported the development of particle composite board made of rice straw and crumb rubber, in the frequency range of 2000–8000 Hz [7]. Gayathri et al, studied the effect of nano silica, crumb rubber and nano clay fillers added to polyurethane foam on sound absorption properties and reported increase in sound absorption coefficient [9]. Numerous efforts been done by researchers [6-11], to develop composite materials with improved sound absorption, physical parameters, and air flow resistivity using recycled rubber and organic wastes as fillers. From literature, it is concluded that addition crumb rubber and coconut coir can be used as effective fillers to improve the sound absorption coefficient of polyurethane foam. Hence, effect of crumb rubber and coconut coir filler addition to the sound absorption capabilities of polyurethane foam at different sound frequencies are investigated.

II. EXPERIMENTAL DETAILS

The conventional and composite polyurethane foam (PUF and CPUF) are prepared by free rise foaming method. PUF was prepared by mixing 100 parts of Polyol, 38 parts of Polyisocyanate (100:38), and stirred mechanically for 15 s. The mixture was then poured into paraffin wax coated mould, the mixture resulted in cream time of 9 s, rise time of 85 s, and gel time of 70 s.

The CPUF was prepared with crumb rubber (1.4 % and 2.0 %) and coconut coir (1.4 % and 2.0 %) as fillers (420 microns) added to the PUF. The foams were allowed to cure for 15-20 minutes before releasing it out of the mould. To determine the acoustical properties of foam, samples of 35 mm diameter and 25 mm thickness were extracted using a conical cutter. The density of the developed foams was determined by measuring the mass and volume of the samples, to find out the density difference due to addition of fillers.

The density was measured on 5 samples, of each composition, and averaged.Sound absorption coefficient (SAC), of the foams was determined using an acoustic test system comprises of a loudspeaker, impedance tube, microphone (1/2 inch pressure field mic), and LMS 32 channel data acquisition system as shown in Figure. 2. The SAC was determined for all foams from samples of diameter 35 mm and thickness of 25 mm, at different frequencies in the range of 100 to 6000 Hz

Noise reduction test (NRT) is done to validate the improvement of SAC. NRT is conducted using a sound impedance tube, were 2 microphones each are placed in front and after the foam sample in the impedance tube. The front and after microphones of 1/2 inch and 1/4 inch pressure field respectively are placed to record the noise before the foam and after the foam sample as shown in Figure 3.

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Figure 1 Photograph of composite polyurethane foam samples

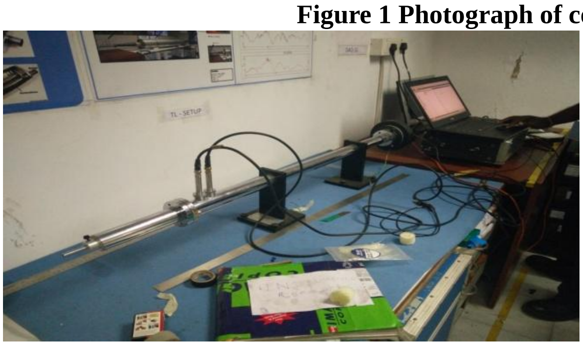


Figure 2 Photograph of Sound absorption coefficient acoustic test system

Figure 3 Photograph of Noise reduction acoustic test system

The microphones obtain the octave curve of the induced sound wave from loud speaker, the induced sound frequencies varies from 100 Hz-6000 Hz. The noise reduction is measured during post processing for the same frequency range.

III. RESULTS AND DISCUSSION

3.1 Foam Density

The density of the developed foams with various % of filler additions are presented in Table 1. The density of the foams increases with increase on filler content for both the filler materials added to the foam. The density of the foam added with coconut coir filler is 1.6 % higher than the crumb rubber added foam.

3.2 Sound Absorption Co-efficient

SAC is observed in two frequency ranges as, from 100 to 200 Hz and 200 to 4000 Hz. The polyurethane foam with no filler addition is set as the baseline against which all the other sound absorption coefficient values were correlated.

3.2 SAC at 100 to 200 Hz

The average SAC value for the polyurethane foam without fillers have an value of 0.30 at the low frequency range of 100 to 200 Hz (refer Fig. 4). The addition of 1.4 % crumb rubber to PUF resulted in increase of average SAC values to 0.4.

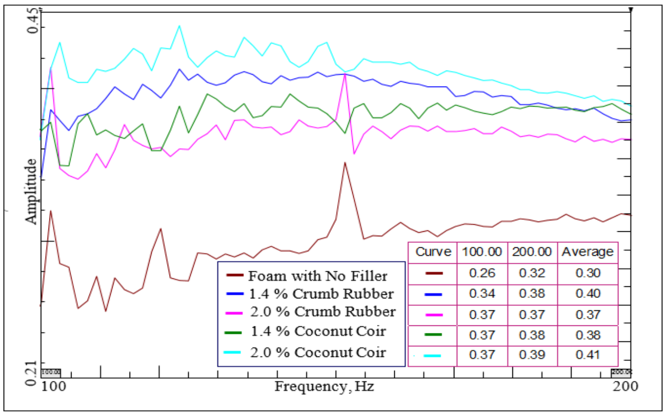


Figure 4 Sound Absorption Coefficient of foams in frequency range from 100 to 200 Hz

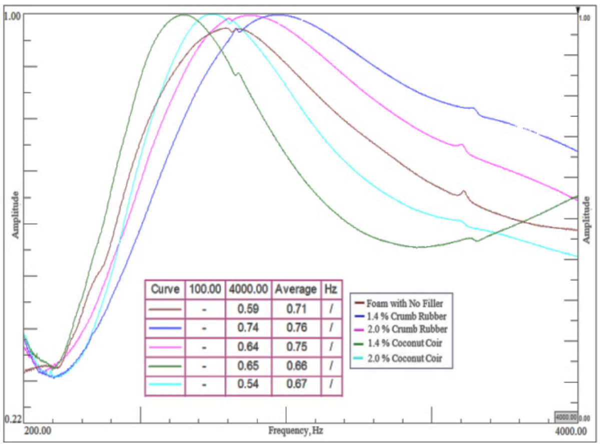


Figure 5 Sound Absorption Coefficient of foams in frequency range from 200 to 4000 Hz

However, with increase in the addition of crumb rubber from1.4 % to 2.0 % the average SAC value drops to 0.37, in the low frequency range of 100 to 200 Hz.

Similarly, the addition of 1.4 % coconut coir as filler to foam also increases the average value of SAC, in comparison to foam with no filler. However, unlike crumb rubber, the value of SAC continues to increase with increase in % of coconut coir filler from 1.4 % to 2.0 %. The highest of average value of SAC (0.41) is achieved by foam with 2.0 % coconut filler.

3.2 SAC at 200 to 4000Hz

The average SAC values of polyurethane foam with no filler at high frequency is higher by 0.41, than it respective of SAC value at low frequency (refer Fig. 5). The average SAC value increase with the addition of crumb rubber filler, while the value decreases with addition of coconut coir in high frequency range.

3.3 Noise Reduction

3.3 a. Effect of Crumb Rubber on Noise Reduction

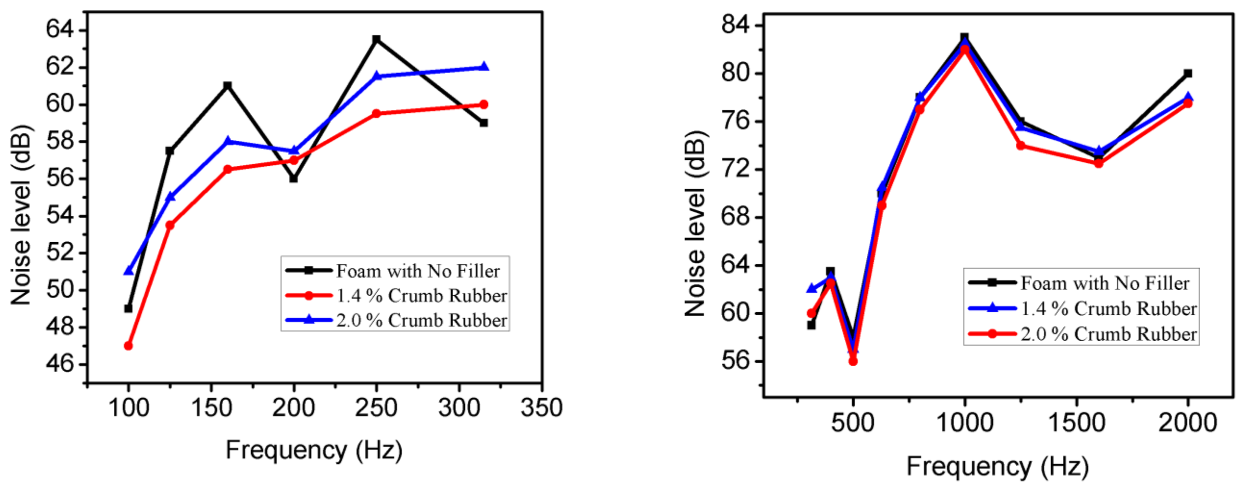
The effect of crumb rubber on noise reduction capabilities of polyurethane foam is shown in Figure 6. The comparison graph of noise levels recorded for polyurethane foams, with crumb rubber filler and no filler during NRT, at low and high frequencies are shown in Figure 6a and 6b respectively. Addition of Crumb rubber as filler to Polyurethane foam is found to be beneficial in noise reduction at lower frequencies (refer Fig. 6a). However, the noise reduction ability of Crumb rubber filler is deteriorating with increase in level of addition from 1.4 % to 2.0 %.

3.3 Effect of Coconut Coir on Noise Reduction

The effect of coconut coir on noise reduction capabilities of polyurethane foam is shown in Figure 7. The comparison graph of noise levels recorded for polyurethane foams, with coconut coir filler and no filler during NRT, at low and high frequencies are shown in Figure 7a and b respectively. The noise reduction achieved by addition of coconut coir filler is substantial at lower frequencies of sound than the reduction achieved at higher frequencies (refer Fig. 7&b). The noise reduction capabilities of the composite foam increases with increase in coconut coir filler addition from 1.4 % to 2.0 %.

IV. DISCUSSION

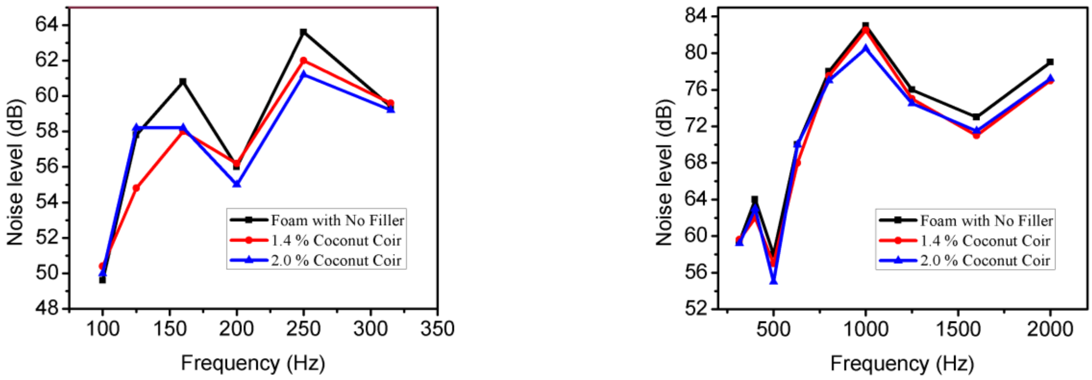
Polyurethane foams are used as sound absorbing materials in acoustic application owing to their viscoelastic nature and the ease of processing. The sound absorption capabilities of polyurethane foam is almost perfect in the high frequency range (>200 Hz), but necessitates improvement in the low frequency range. The addition of crumb rubber and coconut coir filler to polyurethane foam to improve the sound absorption coefficient values at lower frequencies has led to increase in density of the foam (refer Table 1). The designer can rather be judicious in selection of these heavier composite foams for particular



a. Low Frequency

b. High Frequency

Figure 6 Effect of Crumb Rubber on Noise Reduction



a. Low Frequency b. High Frequency

Figure 7 Effect of Coconut Coir on Noise Reduction

application, considering the gains they offer on low frequency sound absorption, and material sustainability.

The filler added to polyurethane foam act as nucleating sites during foaming process and increase the cell density of the foam [12,13]. The sound absorption occurs at the cell/air boundaries and mechanism is reported to be the friction between the air molecules and cell walls [4,14]. The modification in sound absorption characteristics of the foam may be achieved by varying the cell density and the number of cell/air boundaries.The addition of filler to polyurethane foam, both crumb rubber and coconut coir has increased the peak value of the sound absorption coefficient curve (refer Fig. 5). Crumb rubber filler has shifted the peak towards higher frequency, while the coconut coir has shifted the peak towards lower frequencies. However, the shift in peak value of the sound absorption coefficient curve is well within the high frequency range.

The PU foam added with 2.0 % coconut coir and 1.4 % crumb rubber filler has provided the highest sound absorption in low frequency range (refer SAC values in Fig. 4). However, the 1.4 % crumb rubber filler foam provide adequate sound absorption in the higher frequency range too, while it reduces for coconut coir filler added foams (refer SAC values in Fig. 5).

The noise reduction values shown in Fig. 6 validates the superior performance of 1.4 % crumb rubber with lowest noise level of 47 dB at 100 Hz, while the addition of coconut coir filler does not provide any noise reduction at 100 Hz. Further, the increase in addition of crumb rubber filler above 1.4 % to the composite foam deteriorates its noise reduction capabilities. The addition of both fillers to PU foam has provided only minimal noise reduction in the high frequency ranges and remains almost unaltered (refer Fig. 6b&7b).

V. CONCLUSION

1. The sound absorption properties of polyurethane foam at low frequency can be improved by addition of crumb rubber and coconut coir as fillers.
2. The noise reduction properties of polyurethane foam at high frequency is almost unaffected by addition crumb rubber and coconut coir filler up to 2.0 %.
3. The polyurethane foam with 1.4 % crumb rubber offers improved sound absorption coefficient value and noise absorption at low frequency, in combination with lowest density among the composite foams investigated.

ACKNOWLEDGEMENT

The authors wish to acknowledge and place their sincere thanks on record to M/s. Ashok LeylandTechnical Center, Chennai for providing the technical support required to carry out this work.

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