ACOUSTIC PROPERTIES OF RIGID POLYURETHANE FOAM MIXED WITH PET BOTTLE WASTES

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ABSTRACT
Rigid closed-cell polyurethane foam is renowned for its outstanding sound absorption properties and its application as sound insulation panels. Studies show that mixing of rigid polyurethane foam with non-reactive filler materials during fabrication improves the sound absorption properties of the composite material. In this composite, the foam was fabricated from polyol and isocyanate monomers with shredded pet bottle waste as a filler component. The percentages of pet wastes mixed with the polyurethane foam composites varied by 0%, 10%, 15%, 20% and 25% of total weight. The measurement of sound absorption coefficient has been done using the impedance tube technique. The results showed that the rigid polyurethane foam with 0% pet waste has poor acoustic absorption. Also, sound absorption coefficient results showed that a sample with higher amount of upto 20%pet bottle waste had better sound absorption even at higher frequencies. From this research, it is clear that mixing of pet waste as a filler material upto 20% is ideal for fabricating sound absorption panels with better sound absorption average.

Keywords: Sound Absorption, Acoustics, Insulation, Impedance Tube, Sound Absorption Average, PET waste, Rigid Polyurethane Foam

1. INTRODUCTION

The environmental impact of non-biodegradable wastes is increasing drastically due to improper recovery, disposal and management. A large amount of discarded pet bottles that are non-biodegradable is one of the main factors causing plastic pollution. The discrepancies in centralized waste management have been affecting the proper management and utilization of pet waste. Though there are existing methods for recycling pet wastes through depolymerization and polymerization, the energy consumed in the process is very high which makes recycling the waste, not a sustainable approach. The reusal of pet waste through low energy processing can be adopted to make the recovery sustainable. The reuse of the shredded pet waste as a filler material in the manufacture of building material has greater scope in plastic waste management as the energy utilized in the process is minimal. (Berard U & Lannace G, 2015)

In this study, the pet bottle waste is mixed with rigid polyurethane polymer while manufacturing. The major application of rigid polyurethane foam is to develop insulation materials. The rigid polyurethane foam also holds a major part of the insulation material industry. The thermal and sound insulation properties are the factor responsible for its high demand. In this journal, we are measuring the variation in the acoustic properties of the foam when pet waste is mixed with the polymer. Polyurethane systems are one of the most used insulating materials in construction, not only due to their good thermal behaviour but also because of their better acoustic properties. The insulation barrier formed by polyurethane is able to control the annoying sound waves, both those external noises surrounding the building as well as internal noises Noise control is important for a building since it can seriously affect the inhabitant's health. It is one of the four environmental factors with the greatest impact on health. Also, it causes at least 10,000 cases of premature deaths per year in the European Union.

2. MATERIALS

Pet Bottle Wastes: In Kerala, there are decentralised resource recovery centers through which non-biodegradable wastes are collected. The pet wastes which are major cause of pollution are collected, sorted, cleaned and transported to shredding units. The pet bottle wastes were collected from the shredding unit for this study. These shredded pet wastes are to be used as a voluminous filler in rigid polyurethane foam.

Fig 1. Shredding of PET Waste

Isocyanates: Isocyanates used to make polyurethane have two or more isocyanate groups on each molecule. Methylene diphenyl diisocyanate (MDI) is used in the fabrication of rigid foams.

Polyols: Polyols can be further classified according to their end use. Higher molecular weight polyols with molecular weights from 2,000 to 10,000 are used to make more flexible polyurethanes while polyols with lower molecular weight are used in manufacture of rigid polyurethane foam. Polyols having the least molecular weight formulate the maximum rigid polyurethane foam.

Fig 2. Polyols and Isocyanates

Silicon Oil: Silicon oil is used as a lubricant for easy detachment of polymer from the mould. The mould used for the polyurethane manufacturing is coated with a layer of silicon oil. Silicone oil is any liquid polymerized siloxane with organic side chains. The most important member is polydimethylsiloxane.

3. EXPERIMENTAL SETUP

3.1 Weighing Balance:

Specification: Maximum - 220 g, e - 0.001 g and Minimum - 0.1 g, d - 0.1 mg.

Fig 3. Weighing Balance

3.2 Mould:

A circular plastic mould of diameter greater than the diameter of the impedance tube was designed using polyvinyl chloride. The mould is designed in such a way that the foam composite can be detached easily from the mould after polymerisation.

Fig 4. Shaping of Specimen

3.3 Centre lathe:

The Centre lathe is used for decreasing diameter of the specimen so that it suits with the dimensions of impedance tube used for measuring sound absorption.

3.4 Impedance Tube:

Sound-absorption ability of the sample is measured in the plane-wave impedance tube. The sound is generated by a loudspeaker at one end of the tube and the sample is placed and sealed at the other end of the tube. The sound abortion coefficient is the absorbed fraction of the energy of a plane sound wave when incident on the sample material. The coefficient describes the ability of the material to absorb sound in a given frequency band. The impedance tube indigenously designed and developed by Prof. Premlet B was used to measure the sound absorption parameters. (Chanlert & Ruamcharoen, 2020)

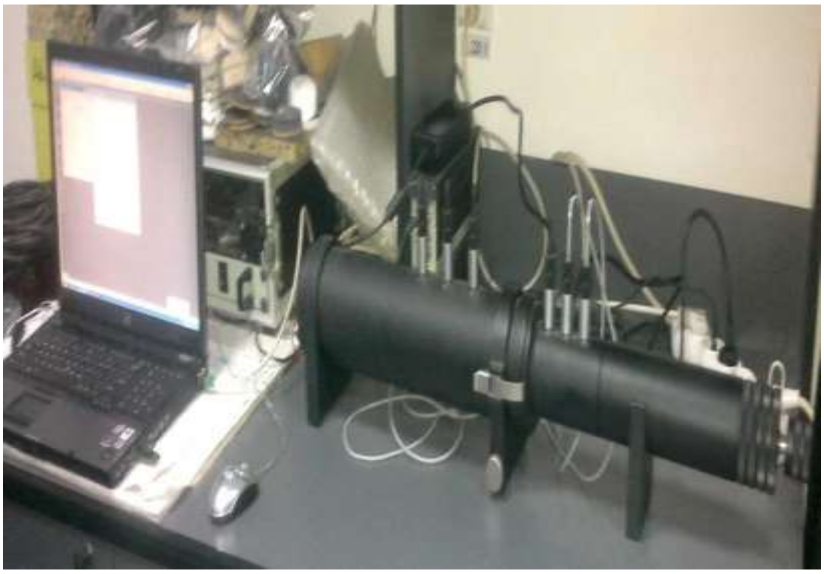

Fig 5. Impedance Tube

4. METHODOLOGY

4.1 Sample Preparation:

Foam composite samples were prepared by mixing rigid polyurethane foam with shredded pet bottle waste. Polyurethane foam which is a thermosetting polymer is manufactured from its monomer's polyol and isocyanate through polymerization by releasing heat. In this study, the shredded pet waste is added to the foam composite just before the mixing of two monomers. The required formulations of polyurethane and pet waste composite were established. This was done by determining the percentage weight of the foam and pet waste that is to be mixed in the composite so as to perform sound absorption tests.

In the first step, the required amount of polyol is taken in the detachable circular PVC mould. The mould is coated with sufficient amount of silicon oil which acts as a surfactant. This makes the removal of composite from the mould easier without any deterioration. To the polyol required percentage of shredded pet waste is added and well mixed before polymerization. Next, the required amount of isocyanate is added to the mixture. The ratio of polyol and isocyanate to be considered while mixing is 1:1.2. The experiment was conducted at a room temperature of about 28-30 degrees Celsius. Instantly after adding isocyanate to the mould the components are thoroughly mixed to maintain homogeneity of foam and in a few minutes, the polymerization of monomers polyol and isocyanate takes place to produce a rigid polyurethane foam composite. The rigid polyurethane foam is then removed from the mould. The size of the specimen is deduced to the required size of specimens as per the standards required for the impedance tube. The diameter of the specimen required is 30 mm while the thickness of the specimen is 50 mm. The diameter of the specimen is acquired by cutting the specimen using a center lathe. The specimen is cut into required thickness using a hack saw.

Table 1. Components of Foam Composites

Sample	Rigid Polyurethane Foam (%)	Pet Bottle Waste (%)	Thickness of Specimen (mm)
PWM0	100	0	50
PWM10	90	10	50
PWM15	85	15	50
PWM20	80	20	50
PWM25	75	25	50

4.2 Sound Absorption Test: The sound absorption test of the foam composites manufactured from rigid polyurethane foam and pet bottle waste is carried out on each sample formulated at a different weight percentage of its components. An impedance tube is utilized to measure the sound absorption coefficient of each sample at different frequencies ranging from 200Hz to 2000 Hz. For every composition of pet waste mixed foam composite four different specimens are made for testing. The average value of sound absorption of four specimens determines the final sound absorption coefficient of each frequency as shown in table 2. (Xiang H F et al., 2013)
The average of the twelve different sound absorption coefficients for one-third octave frequencies ranging from 200 Hz to 2000 Hz gives the sound absorption average of the given material. Thus, the sound absorption average of the foam composite at different weight percentages of pet waste mixed is calculated. The variation in the acoustic properties after mixing with different amounts of pet waste is analysed by measuring its sound absorption coefficients at different frequencies of sound waves. Through this approach, we can determine the suitability of the rigid polyurethane foam composite mixed with shredded PET waste in sound insulation applications such as soundproofing composite panels used in studios and theatres. (Tiuc A et al., 2015)

Frequency (Hz)	Sound Absorption Coefficient (α)				
	0%	10%	15%	20%	25%
500	0.10	0.72	0.47	0.21	0.26
600	0.13	0.18	0.12	0.20	0.15
700	0.15	0.05	0.02	0.02	0.06
800	0.25	0.32	0.52	0.51	0.01
1000	0.32	0.56	0.17	0.37	0.00
1200	0.49	0.03	0.09	0.25	0.04
1400	0.11	0.15	0.28	0.54	0.16
1500	0.06	0.25	0.45	0.59	0.12
1600	0.01	0.38	0.78	0.67	0.11
1700	0.03	0.60	0.31	0.82	0.10
1800	0.39	0.90	0.86	0.85	0.10
1900	0.26	0.96	0.96	0.82	0.09
S f	2.30	5.10	5.03	5.85	1.20
SAA	0.19	0.42	0.42	0.49	0.10

Table 2. Sound Absorption Average

4.3 Sound Absorption Average: The above table consists of variations in the sound absorption coefficient of 12 different one third octave frequencies between 200 and 2000 Hz. The sound absorption coefficient is measured for different PU composite foams mixed with 0%, 10%, 15%, 20% and 25% of pet bottle wastes by weight before polymerisation. The sound absorption average of the composite mixed with different ratios of PET waste is calculated by using the following equations.

$$S_f = \sum_{n=1}^{12} \alpha_n \qquad (1)$$

$$SAA = \frac{S_f}{12} \qquad (2)$$

The sum of sound absorption coefficients at varying frequencies, S_f is calculated as per equation 1. Thereafter sound absorption average, SAA is calculated as in equation 2. The sound absorption average of coefficients computed at different ratios of frequencies is measured for composite foams fabricated at different percentages of pet bottle waste mix which includes 0%, 10%, 15%, 20%, 25% and is denoted as PWM0, PWM10, PWM15, PWM20 and PWM25 respectively. Four samples were tested for each formulation of PET waste so as to improve the accuracy of measurement by taking the average. The sound absorption coefficient at different compositions shows that sound absorption coefficient is better at 10% for high-frequency sound waves. On an average, the sound absorption is optimum for 20% PET waste mixed composite with maximum sound abortion at medium range frequencies of sound waves. At 25% mixed composite there is a sudden drop in sound absorption coefficient.

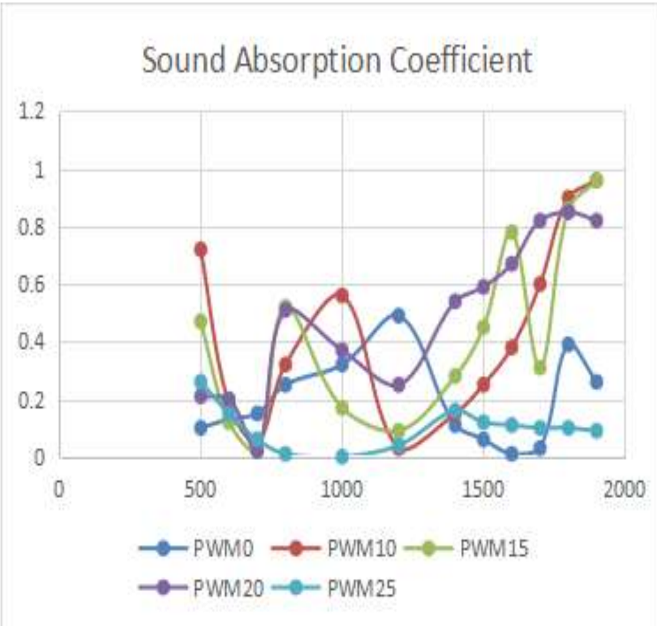

Fig. 6 Sound Absorption Coefficient

Overall PWM20 shows a consistently higher value of sound absorption coefficient across the given frequencies from 1000 Hz to 2000 Hz in the graph shown above. Thus, it is clear that the maximum improvement in the acoustic properties of rigid polyurethane foam is attained when 20 % by weight of shredded pet waste was mixed with the foam composite. The graph also depicts that at a frequency above 1700 Hz the PWM10 composite showed better sound absorption properties compared to other ratios but at this ratio of formulation the composite shows poor insulation at medium frequencies of sound waves. PWM15 also has better sound absorption at higher frequencies than the composite with the highest sound absorption average.

The graph shows the sound absorption coefficient at PWM25 as low throughout the frequencies which determines the extent upto which the shredded pet bottle waste can be mixed with the rigid polyurethane foam without deteriorating the sound insulation properties of the composite material. (Asdrubali F et al., 2012) The given bar graph clearly depicts the variation in the sound absorption average with respect to the percentage by weight of Pet waste mixed in the composite. the material showed a clear enhancement in its sound absorption average at 20 % pet waste mixed foam. After 20% there is a sudden drop in the acoustic properties of the material.

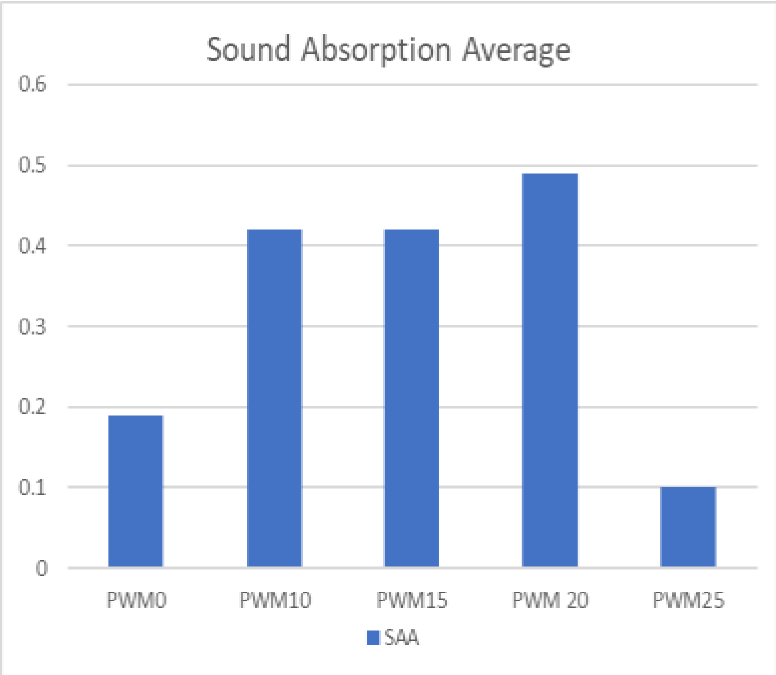

Fig. 7 Sound Absorption Average

So, it is clear that the sound absorption of rigid polyurethane foam can be improved by mixing 20% of pet bottle waste by weight. The higher Sound absorption average of the material makes it ideal to be used in manufacturing sound insulation panels for buildings.

5. RESULTS

The tests conducted on the composite foam show that polyurethane mixed with optimum amount of pet waste has better acoustic properties than polyurethane foam without met waste mixed. The study found that the Sound absorption average can be increased by 60% by mixing with 20% pet waste as a filler material in the foam. Also, the polyurethane PET waste composite with 20% by weight of shredded PET bottle waste mix has a sound absorption average of 0.49. This increase in sound absorption average enhances the utility of the material in the acoustic sector. The introduction of pet waste as filler material helps in reducing the environmental pollution caused by them. While comparing with the conventional methods of pet waste recycling and disposal this method is less energy consuming and efficient. Also, the sustainability aspect of polyurethane foam manufacturing can be enhanced by the addition of pet waste as filler material.

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