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Study of Sound Absorption Properties on Rigid Polyurethane Foams using FEA

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Abstract

Objective: The range of raw material used for the manufacture of Polyurethane using Polyol has grown enormously during the past fifty years. A wide range of products is now available, which allows the researchers to produce, collectively known as Polyurethane Foams as Porous Material. This paper examines the sound absorption properties of porous material from the view point of the manufacturer by the experimental and analysis way. **Method/Analysis:** In this experimental study, finite element method is well established in estimating acoustic transmission loss or sound absorption coefficient of a porous material. Impedance tube is used to measure the acoustic impedance of a sound absorbing porous material, with acoustic source at one end and an acoustic porous material. That is polyurethane foam at other end. There are two common methods used to measure the impedance value of the porous material. The first method involves a moveable microphone that transverses along the impedance tube and the second method is named as "transfer function" or "two-microphone", the two microphone method is followed in this section. In this study, a 3D impedance tube is modelled using finite element software and the results will be compared with experimental data. **Finding:** The effort for this study determines a straight forward route to the production of Rigid Polyurethane foams through a direct reaction process. This system has potentially wide relevance as polyurethane foams. Here, an initial study has shown that using different way to calculate the sound absorption coefficient of a material, either by experimental way or by analysis using FEA software ansys. **Application/ Improvement:** Besides much other application, rigid polyurethane foam is used as acoustic layer in automobile industries, thermal insulation and as energy absorber medium in front bumper of auto motives. Hence by comparing the sound absorption coefficient value of the foam by the both experimental and analysis method we can improve the understanding level and efficiency of the rigid polyurethane foam.

Keywords: 3D Modelling, Finite Element Analysis, Impedance Tube, Rigid Polyurethane Foam, Sound Absorption Coefficient

1. Introduction

Polymer-based foams are widely used in industry to benefit from their mechanical, electrical, thermal and acoustic properties. Polyurethane (PU) is one of the polymers with the largest and most versatile applications having the ability to easily change its properties by changing the chemical composition or adding filler reinforcement agents. It is commonly used in automotive industry as sound absorbing material.

Sound absorption of the material constitutes one of the major requirements for human comfort today, mainly in automobiles and manufacturing environment. This study investigates the effect on sound absorption properties of rigid polyurethane foams by comparing the results modelled 3D impedance tube using finite element analysis and impedance tube experimental data.

The most important acoustic parameter for porous material is sound absorption coefficient. So that material can be classified into two main divisions one is reflective and other one is absorptive. The sound absorption coefficient can be defined as ratio between acoustic energy that was absorbed by a test material and the total incident impinging on the material. The value of sound

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absorption coefficient of the material lies between 0 to 1, 0 for non-absorbent material and for totally absorbent material. Measurement method has been developed in order to study of acoustic properties of different materials. The standard used in this study, are the measurement of impedance tube described in EN ISO 10534:1 and 10534:2.

Using impedance tube method accurate absorbing measurement can be provide for normal incident sounds waves only. At low frequencies the impedance tube method will not give accurate result because the sample must be attached air tightly and allow vibrating freely.

There has been considerable interest in the recent years to improve the methods of measuring the sound absorption coefficient of rigid polyurethane forms by using both experimental and simulation ways, in paper[1] discussed about the microstructure and property of fully and partially closed microporous polyurethane foams and their acoustic behaviour. In[2] analysed that persuasive in improving mechanical and acoustic damping property of polyurethane foam by adding nanotubes which functionalized with amide groups were found to have less impact on property enhancement. In paper[3] concluded the uses of acoustic finite element methods to study acoustic systems having boundary absorption and also used to predict the acoustic behaviour of system having finite dimensions. In paper[4] data which we have been obtain to get empirical relationship between flow resistivity and foam impedance so that it is clearly show us the way to understand the impedance of polyurethane foam. In[5] it is discussed about the strong interface of material thought to be most suitable for straightforward reinforcement may be less desirable for damping applications. In[6] it is clearly mentioned that with the help of Biota–Allard's theory, organized with in approach, can be used to calculate the acoustic behaviour of open-cell polyolefin foam so that sound absorption coefficient of the material is obtained. This study in[7] focused on the mechanical, thermal and recycling properties of a kenaf natural reinforced composites for the consumption in automotive components to increase the efficiency. In paper[8] concentrates on the mechanical and recycling properties of a kenaf long fibre reinforced composites for consumption in automotive components. In paper[9] clearly shows us the improvement of sound absorption coefficient of pure polyurethane foam by adding natural fibres such as tea leave. In[10] it is clearly illustrate the manufacturing process of rigid polyurethane foam.

2. Experimental Arrangement

The experimental study was carried out in aimpedance tube and also by FEA software ansys.

2.1 Production of Rigid Polyurethane Foams

The production of rigid polyurethane foam requires two main liquid components Polyol and isocyanate, along with catalyst, surfactants and blowing agent that are list in Table 1. The blowing agent is usually added to the polyol together with further components such as catalyst (reaction accelerators) and surfactants. The poly-addition reaction that takes place when the polyol and polyisocyanate are mixed together results in Polyurethane structures.

Further details on polyurethane chemistry can be found in “The production of rigid polyurethane foams” by Bayer Material Science.

2.2 Raw Materials used for Polyurethane Reaction

2.3 Production of Test Foam in the Laboratory

Foam rolls with a medium volume are usually produced in the laboratory to determine the chemical properties of a raw material system and the foam density. As the results have to be the same production procedure, reproducible and the same production conditions must be adhered to constantly.

The main ingredients to make polyurethane are isocyanates and polyols, which the isocyanate part is mixed with catalyst and the polyol part is mixed with blowing agent, surfactants, fillers which is clearly shown

Table 1. List of chemical used to make rigid polyurethane foam

Isocyanate	Methylene Diphenylene Di-isocyanate (MDI).
Polyol	Empeyol Polyether Polyols
Blowing agent	Distilled water
Catalyst	Triethylenediamine(TEDA).
Surfactants	Silicon oil

in Figure 1. Before, mixing up of isocyanate and polyol. The amount of isocyanate which is to be added according to the formulation is now quickly weighed into the cardboard beaker with the polyol mixture from the second cardboard beaker. The stirrer process is started, immersed into the liquid at slow running speed. The stopwatch is started at the same time as the stirrer is submerged. The stir time is usually 10 to 15 s. The reaction mix is dispensed into a packaging paper mould immediately after mixing and the cream time, fibre time, rise time and tack-free time are determined. This should not be done until after the foam has cooled which is clearly showed in Figure 2 and Figure 3. By following the above process we can able to obtain the rigid polyurethane foams Figure 4.

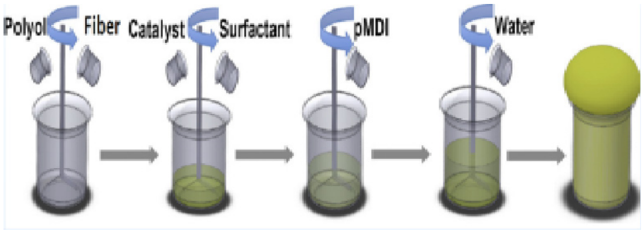

Figure 1. Making of rigid polyurethane foam.

Figure 2. Sample in mould

Figure 3. After curing of polyurethane foam.

2.4 Parameters used in the Analysis of the Impedance Tube

With the application of the two microphone method the impedance tube can able to get reflection coefficient and the normal incidence sound absorption coefficient values by using the parameters which are mentioned by Table 2, Figure 5 shows the experimental setup for impedance tube.

Figure 4. Rigid polyurethane foam in desire shape for impedance test.

Table 2. Parameters used in modelling of impedance tube

Description	Parameter	Value	Units
Length	L	1	m
Width	W	0.1	m
Speed of sound	c_o	343.24	m/s
Density	ρ_o	1.2041	kg/n
Mic 1 location	X_1	-0.4	m
Mic 2 location	X_2	-0.5	m
ANSYS mesh Size	-	0.01	m

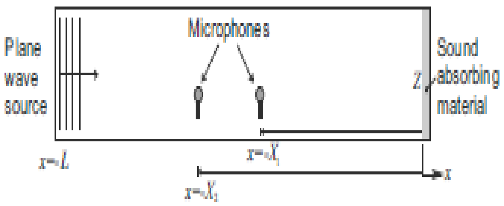

Figure 5. Impedance tube with the two microphone setup.

The sound absorption coefficient of a material, α, is defined as the ratio of sound power absorbed by a surface to the incident sound power. To measure the sound absorption coefficient we can use the below formula

$$\alpha = 1 - |r|^2$$

α – sound absorption coefficient, r – is the complex sound reflection coefficient and is defined as follow Equation:

$$r = \frac{p_r}{p_i}$$

p_r is the reflected pressure, p_i is the incident pressure.

It can be shown that the sound absorption coefficient in terms of the real and imaginary parts of the impedance ratio is given by

$$\alpha = \frac{4R}{(R^2 + X^2) + 2R + 1} = 1 - |r|^2$$

In terms of a real (R is resistance) part and an imaginary (X is reactance) part, the specific acoustic impedance ratio can be calculated.

2.5 Modelling of Impedance Tube using FEM Software Ansys

A 3D test setup was modelled using FEM software Ansys. It was used by default quadratic acoustic elements FLUID220; it will ensure that there are at least 22 elements per wavelength at 1 kHz. The acoustic body is defined by giving speed of sound in air and volume density parameters. On the right side of the tube harmonic mass source is defined by giving amplitude of the mass source. On the left side of the tube acoustic impedance boundary is defined by giving value of resistance and reactance (the tested specimen of polyurethane foam). At two different positions microphone are placed. And the mesh element size of model is 0.01 m shown in Figure 6, to ensure that there are at least 16 elements per wavelength at the highest frequency of interest and also the Figure 7 shows us the pressure level distribution in the simulated impedance tube by using FEM software.

3. Results and Discussions

The study on sound absorption coefficient of rigid polyurethane foam by using impedance tube and ansys software is discussed in the upcoming sections as follows:

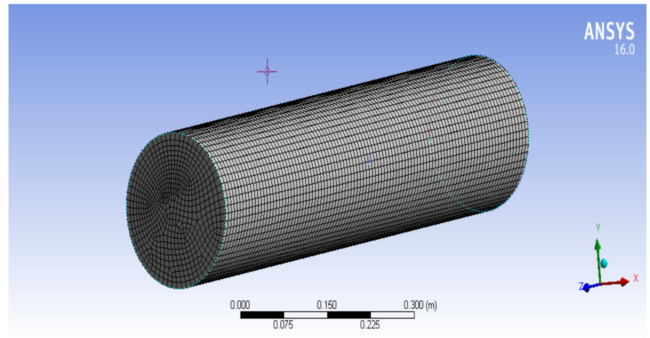

Figure 6. Element size distribution.

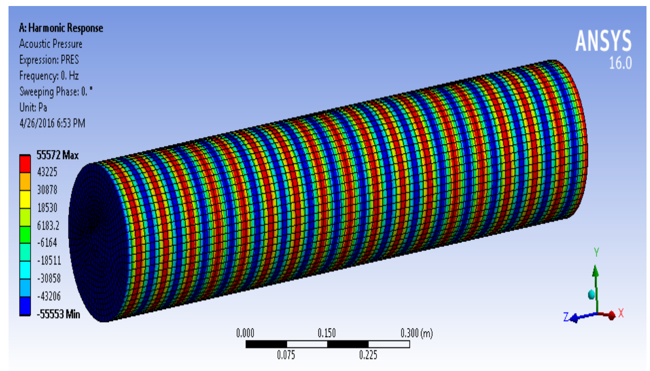

Figure 7. Pressure level distribution.

3.1 Experimental Results using Impedance Tube

The plot comparison between the sound absorption coefficient and frequency of the pure polyurethane foam using impedance tube (two microphone method) is shown in Figure 8.

3.2 Result of Impedance Tube using FEM Software

After the modelling of impedance tube using FEM software ansys with the help of two microphone method we can able to get sound pressure level of both microphone 1 and microphone 2 respectively. Since, we able to find the reflected pressure level from Microphone1 from Figure 9 and the incident pressure level from Microphone2 from Figure 10, the sound absorption coefficient α, are calculated by using formula

By interpreting Figure 9 and Figure 10 we can able to get the value of sound pressure level of microphone 1 and microphone 2 with the respective frequency range of 0 to 6000 Hz. Hence the Figure 11 shows us the sound absorption coefficient of a material using FEA software ansys.

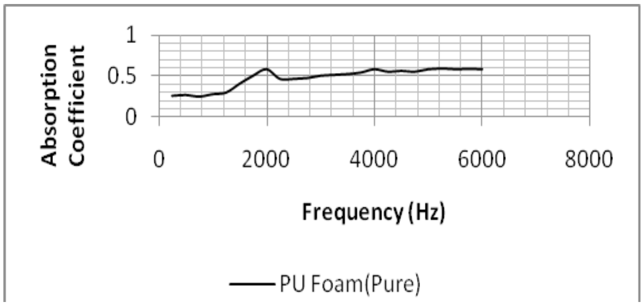

Figure 8. Sound absorption coefficient of PU foam with respective frequency range.

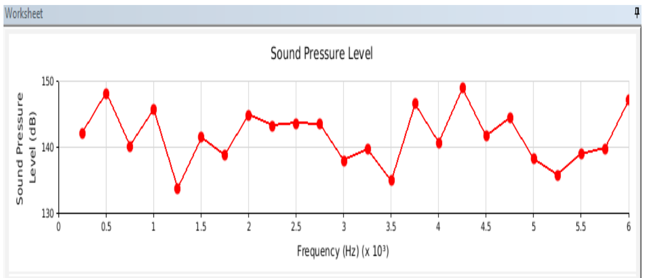

Figure 9. Sound pressure level of microphone 1.

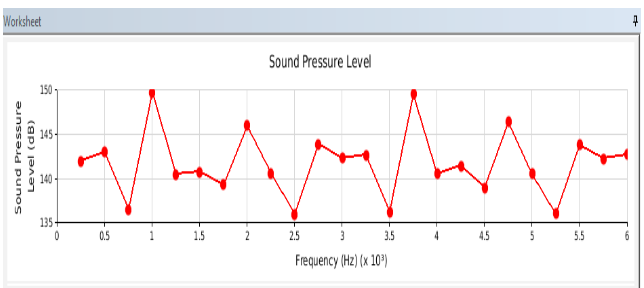

Figure 10. Sound pressure level of microphone 2.

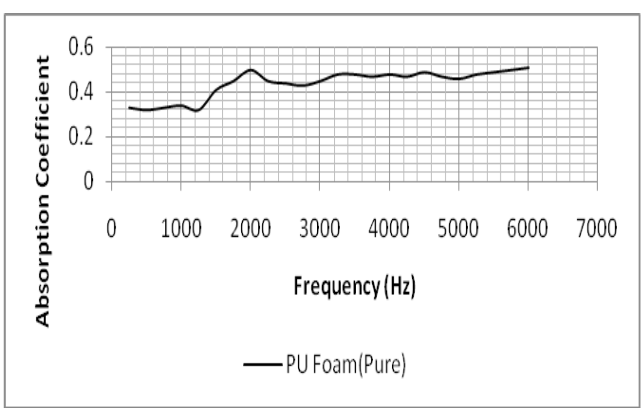

Figure 11. Sound absorption coefficient of PU foam with respective frequency range using FEA software ansys.

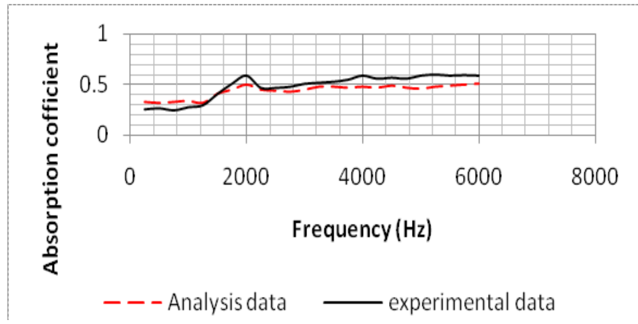

Figure 12. Comparisons between experimental data and analysis data.

3.3 Results Comparison of Experimental Data and Analysis Data

The results obtained from the experimental data and analysis data are interpreted, and compared the difference in results which is clearly shown Figure 12.

4. Conclusion

In general, there is a wide range of acoustical enactment of altered materials available for sound absorption in the interior of an automobile. As material changes are made, the performance of the materials needs to be carefully matched either by modeling or material testing.

The effort for this study determines a straight forward route to the production of Rigid Polyurethane foams through a direct reaction process. This system has potentially wide relevance as polyurethane foams. Here, an initial study has shown that using different way to calculate the sound absorption coefficient of a material, either by experimental way or by analysis using FEA software ansys.

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