Development of Nonwoven Composites for Acoustic Applications

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Abstract
The fashion industry has seen a significant growth in the number of fashion shows taking place per year. The Lakme Fashion Week, Wills Lifestyle India Fashion Week, India Bridal Fashion Week and many more such fashion weeks are organized each year in halls and auditoriums. Most of the times parallel fashion shows are conducted in adjacent halls. Acoustic designing of these halls is of great importance for disturbance free results and viewer satisfaction. Disturbances within the hall can be caused by reflections from the walls and ceiling and also due to the echoes produced by objects and articles present in the hall. Disturbances between the halls can be caused due to the leakage of sound from doors or other openings. All the existing solutions available for minimizing these acoustic disturbances are either very thick or heavy or needs to be used in combination with other materials which reduces the cost effectiveness, the most commonly used materials being fiber glass, foam, partitions, etc. To overcome this disadvantage, in the present study, an attempt has been made to develop a ready to use nonwoven composite material manufactured by stitch bonding different nonwoven fabrics into a single structure. Nonwoven fabrics of polyester are used for making the nonwoven composite. The nonwoven composite developed in this study are tested for sound absorption and transmission loss as per the ISO 10534-2 and ASTM 2611 respectively. The results showed that the developed nonwoven composite is at par with the existing materials available for acoustics. The material provides combination of both sound absorptive as well as sound reflective properties along with the added advantage of reduced thickness. The nonwoven composite also proves to be a one-stop solution for most of the acoustic applications.

Keywords: *Acoustics, Nonwoven composites, sound absorption, stitch bonding, transmission loss*

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1. Introduction

Acoustic designing of halls, especially during adjacent fashion shows, is of great importance for disturbance free results and viewer satisfaction. Disturbances within the hall can be caused by reflections from the walls and ceiling and also due to the echoes produced by objects and articles present in the hall. Disturbances between the halls can be caused due to the leakage of sound from doors or other openings. The present study was undertaken to provide an efficient, cost effective and one-stop solution to these acoustic disturbances.

1.1 Research problem

The existing acoustic solution offered by various companies, require the use of combination of different layers of various materials to be fixed one by one with the help of adhesives. These different materials include a ply wood, a thick nonwoven backing, a glass wool fabric and the outer layer for aesthetic purpose. Fixing these layers is a tedious job and requires lot of time and efforts. Also, for excellent sound absorption properties, the material needs to be porous. The existing acoustic solutions use adhesives to fix the materials together. The adhesive materials reduce the porosity of these combinations of materials, which leads to the reflection of sound back to the hall. In order to overcome these problems, the researcher had undertaken a study to develop a one-stop solution and replacement for existing acoustic solutions.

1.2 Literature review

Acoustics deals with the scientific study of sound which includes the effect of reflection, refraction, absorption, diffraction and interference. Absorption coefficient is defined as the fraction of randomly incident sound energy which is absorbed by the surface. The basic parameters of acoustic materials are the impedance and the surface shape. The law of conservation of energy states that energy can neither be created nor destroyed, but it can change from one form to another. Absorption converts sound energy into heat energy. It is useful for reducing sound levels within rooms but not between rooms. Each material with which a sound wave interacts absorbs some sound. The most common measurement of that is the absorption coefficient, typically denoted by the Greek letter α.The absorption coefficient is a ratio of absorbed to incident sound energy. The reflection coefficient is a ratio of reflect to incident sound energy. A material with absorption coefficient 0 reflects all sound incident upon it. If a material absorbs all sound incident upon it, its absorption coefficient is 1. In practice, all materials absorb some sound, so this is a theoretical limit [1].

The phenomenon of persistence of sound due to multiple reflections from the ceiling, floor, walls and other material objects in an enclosure is called reverberation. Reverberation time (RT) may be defined as the time required from the moment of cessation of sound for the intensity to drop by 60 dB. Research has shown that it is the initial portion of the sound decay curve process which is responsible for our subjective impression of reverberation as the later portion is usually marked by new sounds. For this Early Decay Time (EDT) is used. This is measured in the same way as the normal RT but over only the first 10-15 dB of decay, depending on the work. The optimum reverberation time of an auditorium is dependent on the use for which it is designed. The reverberation time of auditorium should be long enough at around 1.5 s to 2.5 s and this time should be longer for low frequency sound and shorter for high frequency sound [2].

Although, almost all materials possess some amount of sound absorption property, acoustic materials are those that can absorb the majority of the sound energy impinged on them. Acoustic materials can be used to control and reduce the noise levels from various sources. These materials absorb and dissipate the energy converting some into heat when sound travels through them. Acoustic materials can be of two types such as (a) noise absorption type and (b) noise reduction type. The former class of materials works by suppressing the sound, whereas the latter class works by reducing the sound energy when it passes through them. Acoustic materials reduce the energy of sound waves before it is reached with the receptor. Several methods can be used to reduce the sound such as: (a) use of acoustic barriers that can absorb sound energy, (b) increasing the distance between the source and receptor, (c) use of sound baffles and (d) use of anti-noise sound generators [3].

Acoustical materials play a number of roles that are important in Acoustic engineering such as control of room Acoustics, industrial noise control, sound studio acoustics and automotive acoustics. [3, 8] describe the sound absorptive materials generally used to counteract the undesirable effects of the sound reflection by hard, rigid and interior surfaces and thus help to reduce the reverberant noise levels. They were used as interior linings materials for auditoriums, halls, apartments, automotive, aircrafts, and ducts and encloses for noise equipments and insulations for machineries.

Acoustic treatments are used for a variety of buildings in various forms. For example:

- Educational buildings, learning centers, common areas, auditoriums or lecture theatres.
- Community areas such as churches, chapels, airports and travel hubs.
- Entertainment rooms such as theatres, clubs and art galleries.
- Commercial applications such as call centre cubical, meeting or conference rooms.
- Residential settings such as home theatre rooms or houses that are near heavy noise sources like a freeway to control the internal or external noise level.
- Residential buildings closer to airports or highways with excess noise.

An auditorium is an indispensable one for performing arts, music concerts and various social functions. Acoustic and thermal comforts are the figures of merit of such a building. One purpose of the acoustic retrofitting or acoustic treatments in auditoriums is to absorb unwanted noise echoing and to confine the sound inside the room, avoiding any disturbance to neighbours. Another purpose is to restrict the entrance of unwanted noise into the room and to avoid disturbances.

Acoustic baffle systems are widely used in conference rooms, shopping mall lobbies, lecture theatres, warehouses or even car parks to reduce the internal noise level. Acoustic baffle systems are usually made of panels of sound absorbent material such as wood panel, cellular foam material, and they are used in large rooms and lobbies with ceilings of an adequate height and a large volume. Baffle systems are designed with continuously changing the size and the shape of the baffles and the stance between them to allow for maximum sound attenuation. The foam type lighter materials are chosen and the panel thickness, panel edge shape is considered to provide an efficient sound attenuation while the color is chosen to add to an enhanced visual image [4].

Absorbent materials are usually elastic, not very dense and permeable. They are formed mostly by air. These are soft or fibrous materials containing fine channels interconnected with each other. They can absorb acoustic energy through two mechanisms: when they are soft materials, they absorb due to the deformation that occurs when the sound wave hits them. When they are porous materials, they absorb by the vibration of the air contained in its pores, which loses energy by friction against their edges. A detailed list of materials used in auditorium is given in table 1[5].

Table 1: Sound absorbing materials used in auditoriums

Sr. No.	Sound absorbing material	Sr. No.	Sound absorbing material
1.	Wood	12.	Acoustic plasters
2.	Glass wool	13.	Acoustic tiles
3.	Foam	14.	Strawboard
4.	Acoustic fiberglass	15.	Pulp boards
5.	Acoustic cotton	16.	Compressed fiber boards
6.	Acoustic foam	17.	Compressed wood particle board
7.	Acoustic partitions	18.	Perforated plywood
8.	Hanging baffles	19.	Wood wool board
9.	Water resistant panels	20.	Quilts
10.	Echo absorbers	21.	Mats
11.	Wooden panels		

Table 2 - The acoustical properties of some conventional and sustainable materials [6]

Sr. No.	Materials	Thickness (mm)	Density (kg/m^2)	Absorption coefficient (α)			
				250 Hz	500 Hz	1000 Hz	2000 Hz
1	Glass wool	50	50	0.45	0.65	0.75	0.80
2	Rock wool	50	80	0.29	0.52	0.83	0.91
3	Polystyrene	50	28	0.22	0.42	0.78	0.65
4	Polyurethane	50	30	0.30	0.68	0.89	0.79
5	Polyethylene	50	32	0.25	1.00	0.40	0.70
6	Polyester	45	20	0.56	0.85	0.98	0.95
7	Hemp fibers	40	40	0.59	0.60	0.56	0.52
8	Kenaf fibers	50	50	0.48	0.74	0.91	0.86
9	Mineralized wool fibers	50	470	0.25	0.65	0.60	0.55
10	Flax	35	43	0.66	0.84	0.79	0.53
11	Coconut fibers	35	70	0.28	0.40	0.64	0.74
12	Reed grating	50	130	0.46	0.86	0.71	-
13	Sheep wool	60	25	0.24	0.38	0.62	0.84
14	Cellulose	50	28	0.60	0.90	0.75	0.53
15	Rubber grains	5	1400	0.20	0.82	0.50	0.56

2. Methodology

To conduct the study, following methodology was adopted:

1) Theoretical review of existing acoustic materials used in auditoriums
2) Sourcing of nonwoven fabrics for acoustic application
3) Stitch bonding of two and three layers of nonwoven fabrics to form nonwoven composites

4) Testing of samples for properties like thickness, areal density and volumetric density
5) Testing of nonwoven composites on acoustic impedance tube to measure absorption coefficient and transmission loss
6) Comparative analysis of the results obtained

Sample Preparation

P1 **P2** **P3** **P4** **P5**

Figure 1: Polyester Nonwoven Samples

As shown in figure 1, for the present study, five different polyester needle punched nonwoven fabrics were selected. The fabrics were cut in circle of diameter 100 mm by a laser cutting machine. Two and three layers of the fabrics samples were than manually stitched bonded using a polyester sewing thread.

Preliminary Properties

The nonwoven fabric samples were tested for the measurement of thickness and GSM on thickness gauge and weighing balance respectively as per ASTM standards. Volumetric density and porosity was calculated theoretically using the following equation 1 and 2 respectively:

$$Volumetric\ density\ (g/cc) = \frac{Areal\ density\ (gsm)}{Thickness\ (mm) \times 100} \qquad \text{(Equation 1)}$$

$$Porosity = \frac{1 - volumetric\ density}{fiber\ density} \qquad \text{(Equation 2)}$$

Fiber density of polyester is taken as 1.38 g/cm^3

Acoustic impedance tube testing procedure

The sample was mounted on the sample holder of the tube and the holder was kept at a distance of 150 mm from the microphone. The sound source was at a distance of 350 mm from the test sample. The tests were carried out using a MATLAB programme designed specifically for the impedance tube setup. The effective testing frequency range of the setup was 0.1 kHz to 3.5 kHz. The sound absorption coefficient was calculated using the following equation 3:

$$\alpha = 1 - 10^{-\left(\frac{d}{20}\right)} \qquad \text{(Equation 3)}$$

Where, α = sound absorption coefficient, *d* = difference between empty reading and sample reading.

Noise reduction coefficient (NRC) and noise attenuation are the parameters that describe the ability of these materials to reduce the noise. NRC represents the amount of sound energy absorbed by a material when sound wave strikes a particular surface, which ranges from 0 to 1. A NRC value of 0 indicates perfect reflection; whereas a NRC of 1 indicates perfect absorption. NRC is measured by acoustic instruments using frequencies of 250, 500, 1000 and 2000 Hz.

3. Analysis & Findings

The preliminary results obtained by testing the samples are given in table 2.

Table 2: Preliminary test results

Fabric No.	Thickness (mm)	Areal Density (gsm)	Volumetric Density (g/cc)	Theoretical Porosity
P1	3.50	290	0.083	0.66
P2	4.00	300	0.075	0.67
P3	5.00	415	0.083	0.66
P4	5.00	900	0.180	0.59
P5	6.00	700	0.117	0.64

The test results obtained for the single layer of fabrics tested for their acoustic behavior are given in table 3:

Table 3: Acoustic behavior of single layer nonwovens

Frequency (kHz)		0.1	0.25	0.5	1.0	1.5	2.0	2.5	3.0	3.5	NRC
ER (dB)		69.8	88.0	89.1	77.1	83.0	82.4	65.7	83.8	78.6	
P11	SR (dB)	69.4	86.7	89.1	76.7	82.7	81.9	65.5	83.5	77.7	0.06
	SAC	0.05	0.14	0.00	0.05	0.03	0.06	0.02	0.03	0.10	
	TL (dB)	0.4	1.3	0.0	0.4	0.3	0.5	0.2	0.3	0.9	
P21	SR (dB)	64.9	85.9	89.1	75.6	81.7	79.1	65.2	79.1	76.9	0.17
	SAC	0.43	0.21	0.00	0.16	0.14	0.32	0.06	0.42	0.18	
	TL (dB)	4.9	2.1	0.0	1.5	1.3	3.3	0.5	4.7	1.7	
P31	SR (dB)	65	85.9	88.9	74.1	79.3	76.5	64.8	77.5	75.9	0.25
	SAC	0.42	0.21	0.02	0.29	0.35	0.49	0.10	0.52	0.27	
	TL (dB)	4.8	2.1	0.2	3.0	3.7	5.9	0.9	6.3	2.7	
P41	SR (dB)	62.8	82.5	88.8	73.7	78.7	75.3	63.2	77.7	75.3	0.34
	SAC	0.55	0.47	0.03	0.32	0.39	0.56	0.25	0.50	0.32	
	TL (dB)	7.0	5.5	0.3	3.4	4.3	7.1	2.5	6.1	3.3	
P51	SR (dB)	64.4	84.7	89.1	75.7	81.5	78.8	63.0	78.6	76.3	0.20
	SAC	0.46	0.32	0.00	0.15	0.16	0.34	0.27	0.45	0.23	
	TL (dB)	5.4	3.3	0.0	1.4	1.5	3.6	2.7	5.2	2.3	

*ER = Empty reading, SR = Sample reading, SAC = Sound absorption coefficient, TL = Transmission loss, NRC = Noise reduction coefficient

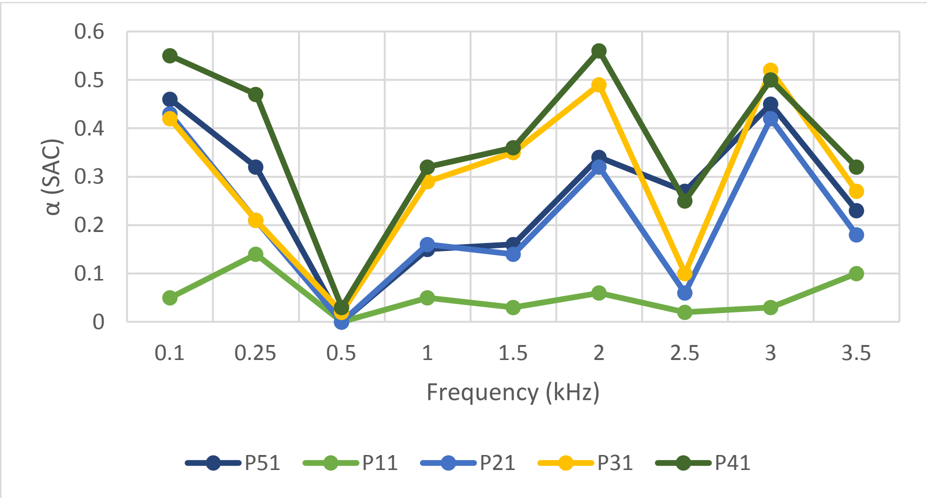

Figure 3: Acoustic behavior of single layer nonwovens

Table 3 and figure 3 suggests that low transmission loss and hence low sound absorption coefficient was observed for the single layer nonwoven samples. More noise was able to pass through the sample which is disadvantageous since more noise will escape from the hall, causing disturbance to the adjacent halls. Though samples P31 and P41 are shows better acoustic behavior in the frequency range of 1000 Hz to 3000 Hz, than other samples. This is because of the higher areal density of the fabrics leading to loss of permeability compared to other fabrics.

Table 4: Acoustic behavior of double layer nonwoven composites

Frequency (kHz)		0.1	0.25	0.5	1.0	1.5	2.0	2.5	3.0	3.5	NRC
ER (dB)		69.8	88.0	89.1	77.1	83.0	82.4	65.7	83.8	78.6	
P12	SR (dB)	68.6	85.3	88.9	75.4	79.7	78.4	61.4	82.4	78.0	0.21
	SAC	0.13	0.27	0.02	0.18	0.32	0.37	0.39	0.15	0.07	
	TL (dB)	1.2	2.7	0.2	1.7	3.3	4.0	4.3	1.4	0.6	

P22	**SR (dB)**	64.2	83.6	89.1	74.7	78.1	74.4	61.1	74.1	72.9	0.31
	SAC	0.48	0.40	0.00	0.24	0.43	0.60	0.41	0.67	0.48	
	TL (dB)	5.6	4.4	0.0	2.4	4.9	8.0	4.6	9.7	5.7	
P32	**SR (dB)**	63.7	84.5	88.9	73.7	79.0	75.7	63.2	76.9	75.7	0.30
	SAC	0.50	0.33	0.02	0.32	0.37	0.54	0.25	0.55	0.28	
	TL (dB)	6.1	3.5	0.2	3.4	4.0	6.7	2.5	6.9	2.9	
P42	**SR (dB)**	62.1	79.9	88.8	70.3	74.6	70.3	58.3	72.3	70.6	0.48
	SAC	0.59	0.61	0.03	0.54	0.62	0.75	0.57	0.73	0.60	
	TL (dB)	7.7	8.1	0.3	6.8	8.4	12.1	7.4	11.5	8.0	
P52	**SR (dB)**	63.4	81.0	89.0	74.5	80.3	76.5	61.5	76.3	76.1	0.33
	SAC	0.52	0.55	0.01	0.26	0.27	0.49	0.38	0.58	0.25	
	TL (dB)	6.4	7.0	0.1	2.6	2.7	5.9	4.2	7.5	2.5	

*ER = Empty reading, SR = Sample reading, SAC = Sound absorption coefficient, TL = Transmission loss, NRC = Noise reduction coefficient

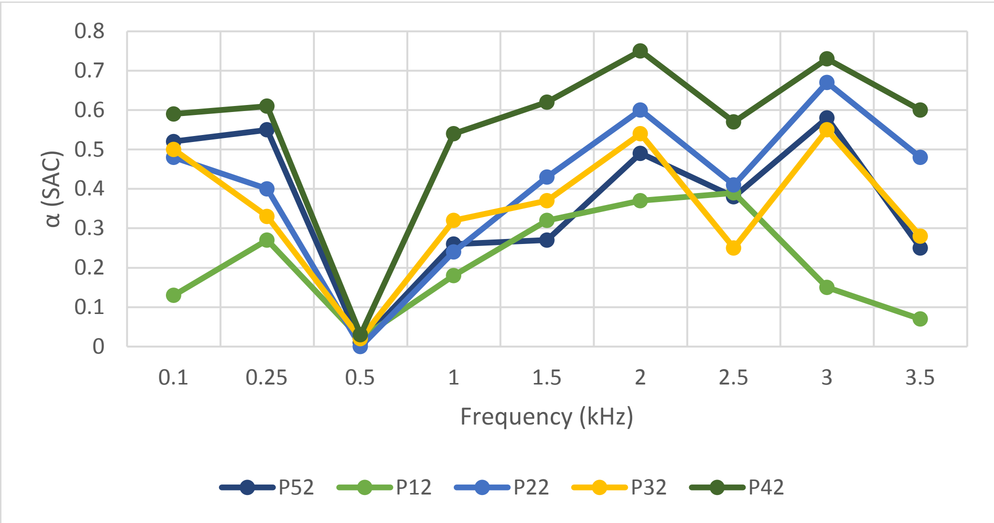

Figure 4: Acoustic behavior of double layer nonwoven composites

Table 4 and figure 4 advocates that fair transmission loss and sound absorption coefficient was observed for the double layer nonwoven composite samples. Compared to single layer fabrics, less noise is able to leak through the samples, which is one of the requirements for a sound proof auditorium. This will lead to less disturbances in the adjacent and nearby halls and rooms. Samples P42 behaves excellently at all frequencies, showing absorption coefficient above 0.5. Combination of two layers has increased the areal and volumetric density of the fabric leading to less air permeable fabrics. This also suggests that there is a significant improvement in the acoustic behavior of double layer composite nonwovens compared to single layer nonwovens.

Table 5: Acoustic behavior of triple layer nonwoven composites

Frequency (kHz)		**0.1**	**0.25**	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**NRC**
ER (dB)		69.8	88.0	89.1	77.1	83.0	82.4	65.7	83.8	78.6	
P12	**SR (dB)**	64.9	84.7	89.1	75.3	81.1	77.5	61.3	77.6	77.1	0.24
	SAC	0.43	0.32	0.00	0.19	0.20	0.43	0.40	0.51	0.16	
	TL (dB)	4.9	3.3	0.0	1.8	1.9	4.9	4.4	6.2	1.5	
P22	**SR (dB)**	64.1	81.4	88.9	73.3	78.1	73.8	61.0	74.5	75.9	0.38
	SAC	0.48	0.53	0.02	0.35	0.43	0.63	0.42	0.66	0.27	
	TL (dB)	5.7	6.6	0.2	3.8	4.9	8.6	4.7	9.3	2.7	
P32	**SR (dB)**	63.1	83.6	88.9	73.4	78.5	74.5	63.0	76.7	75.5	0.34
	SAC	0.54	0.40	0.02	0.35	0.40	0.60	0.27	0.56	0.30	
	TL (dB)	6.7	4.4	0.2	3.7	4.5	7.9	2.7	7.1	3.1	
P42	**SR (dB)**	62.4	79.1	89.1	74.4	79.5	75.0	58.1	73.9	76.1	0.37

	SAC	0.57	0.64	0.00	0.27	0.33	0.57	0.58	0.68	0.25	
	TL (dB)	7.4	8.9	0.0	2.7	3.5	7.4	7.6	9.9	2.5	
P52	**SR (dB)**	62.4	78.7	89.0	72.2	76.4	72.0	61.3	71.3	75.7	0.41
	SAC	0.57	0.66	0.01	0.43	0.53	0.70	0.40	0.76	0.28	
	TL (dB)	7.4	9.3	0.1	4.9	6.6	10.4	4.4	12.5	2.9	

*ER = Empty reading, SR = Sample reading, SAC = Sound absorption coefficient, TL = Transmission loss, NRC = Noise reduction coefficient

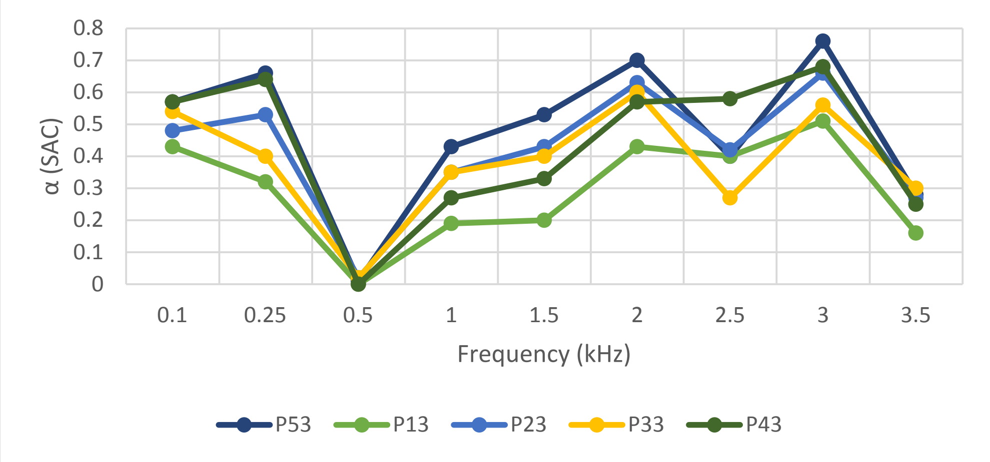

Figure 5: Acoustic behavior of triple layer nonwoven composites

Table 5 and figure 5 indicates that an average value of transmission loss and sound absorption coefficient was observed for the triple layer nonwoven composite samples. But compared to double layer nonwoven composites, it can be seen that there is no significant improvement in the acoustic behavior of triple layer nonwoven composites. This is because, the maximum attenuation of the sound energy takes place till the second layer, and hence the addition of the third layer does not significantly reduce the sound energy. Hence addition of the third layer to the nonwoven composite is not a cost effective option. Again, samples P32, P42 and P52 behave better than other samples almost at all frequencies.

The below given figure 6 shows comparative data of the P4 sample, which shows good acoustic behavior at all frequencies for single, double and triple layer nonwoven composites. It can be clearly seen that the sample P42 behaves very well compared to the samples P41 and P43.

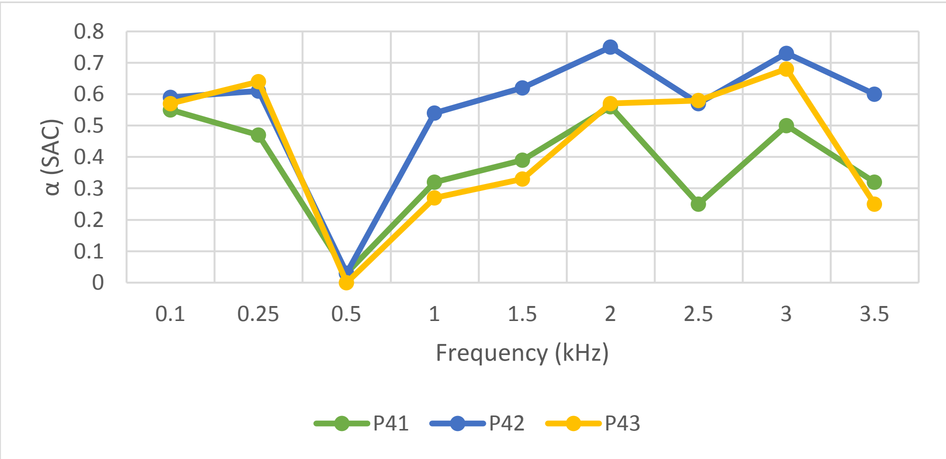

Figure 6: Comparison of acoustic behavior of P4 sample

4. Conclusions

Nonwoven fabrics of polyester were used for making the nonwoven composite by stitch bonding of two and three layers. The nonwoven composite developed in this study were tested for sound absorption and transmission loss as per the ISO 10534-2 and ASTM 2611 respectively. The results showed that the developed nonwoven composite is at par with the existing materials available for acoustics specifically in the range of 1000 Hz to 3500 Hz. The double layer nonwoven composites is the most efficient option for effective sound attenuation and damping. The developed nonwoven composite provide combination of both sound absorptive as well as sound reflective properties along with the added advantage of reduced thickness. The nonwoven composite also proves to be a one-stop solution for most of the acoustic applications.

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