Analysis of the effect of fabric parameters on sound related properties of blended fabrics

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T. S. Niroshan, J.W.A. Madushika, S.N. Niles

Abstract: Sound is a form of energy which is carried by sound waves. Sound may be reflected, transmitted, absorbed or diffused. Various applications may require the absorption or reduced transmission or reflection of sound. Textile fabrics have been used extensively for this purpose. Non-woven fabrics with different properties play a significant role in sound related properties because of their high porosity, low cost, low weight and low environmental impact. Despite this fact, woven and knitted fabrics are preferred in some sound related end-uses where nonwoven and spacer textiles cannot be used economically and due to aesthetic aspects. The aim of this research is to analyse how sound related properties of Polyester/Cotton blended fabrics would vary with different fabric parameters, namely thickness, composition and areal density. For this study a low cost impedance tube was built and experiments were carried out using the equipment developed. The frequency of the emitted sound was varied and their pressure levels monitored and converted to required parameters. The effect of thickness, composition and areal density on sound related properties of woven fabrics was investigated. The test results showed that, in case of increasing the thickness, the sound absorption and reflection coefficients of fabrics increased at low frequencies and slightly decreased at high frequencies. The transmission characteristics were opposite to that. 100% polyester had the highest sound absorption and the 100% cotton fabric had the second highest sound absorption. Moreover, test results revealed that denser fabrics absorb more sound waves than reflection or transmission in high frequencies.

Keywords: Sound Reflectance, Sound Transmission, Sound Absorption, Sound Diffusion, spacer textiles, areal density, impedance tube, acoustic textiles.

1. Introduction

Rapid development of science and technology has led to the advent of numerous inventions intended to enhance life comfort. This had both positive and negative consequences. One of the noticeable negative impacts is sound pollution, termed as environmental noise, which adversely affects the physiology, psychology and performance of human to a greater extent. Thus, sound reduction and insulation is of significant importance for the well-being of people.

Sound is a result of vibration, and is an important part of human life. It can be defined as a motion in an elastic media, which can be air, water or solid [1]. The sound wave transfers the energy to the relevant media and in return energy will be carried by the sound wave as well. When a sound wave hits a surface, it can react in four major ways: it can be reflected, absorbed, transmitted and diffused. This sound can result in noise which causes considerable annoyance and even damage to living beings. The audible range of sound frequencies of a human is usually 20Hz to 20kHz [1]. If these audio waves appear in a random spectrum or, in other words, if they are undesired sounds, they are called “noise”.

Noise greatly affects day-to-day activities and can even cause various health problems such as sleep disturbance, hearing loss, a decrease in

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productivity, learning ability and an increase in stress related hormones and blood pressure. Therefore noise should be controlled for human comfort and health.

Materials used for constructions normally have some acoustic properties such as absorption, reflectance, transmittance and diffusion. When a sound wave strikes on a surface some amount of energy is absorbed by the material [2]. The sound can be absorbed in a porous material and it can be explained as sound waves bouncing off the walls inside the voids in the porous material until they have lost their absorbed energy. This can happen mainly in three ways, namely thermal losses, momentum losses and heat conduction [2]. Some amount of sound waves is reflected and they can interfere with incident waves, producing patterns of constructive and destructive interference. This happens when the sound wave hits a surface that is hard and compact with acoustic impedance that is very different from the sound wave. The reflection angle of a sound wave from the reflecting surface is equal to the angle of incidence. When a material has similar impedance as air the sound wave propagates without reflection or absorption [3]. This is known as sound transmittance. When sound wave strikes in an uneven or convex surface, then sound waves spread in different angles. This is called as diffusion [3].

Textiles such as nonwoven, woven and knitted fabrics are widely used in sound-related applications as they have high porosity, low cost, low weight and low environmental impact. Nonwoven structures are the preferred medium for sound insulating and sound absorbing applications as they contain pores in micron and submicron scale [4]. They are commonly used as noise absorption elements in a wide range of applications including acoustic ceilings, noise reducing quilts, and noise proof barriers. However, it is difficult to produce a textured surface for nonwovens with an aesthetically pleasing appearance. So nonwoven fibre webs are usually draped with a woven fabric. Plain weft knitted fabrics have low noise absorption. The sound absorption of a single layer of a plain knitted fabric is poor; in order to increase its noise absorption properties the structure has to be made thicker and denser (it can be done by knitting with a smaller stich length). However, at the higher end of the spectrum, other knitted structures such as rib, interlock, textured and ripple structures will make the fabric thicker and improve the noise absorption [5]. According to researchers, combinations of weft-knitted and warp-knitted spacer fabrics can highly improve their sound absorbability, but their arrangement sequence has a significant effect. A woven fabric without any other structure shows low noise absorption [6]. But using it with an air gap between the woven fabric and the hard acoustic structure can improve the noise absorption [7]. Theatre curtains are one of such application that commonly uses woven fabrics.
There are several physical parameters that have considerable impact on the sound related properties of woven fabrics. The properties like thickness, porosity and areal density play a significant role in determining the sound related characteristics. Moreover, the linear density, weave types, composition and air gap have some remarkable impact [8]. For this particular study the thickness, composition and areal density were selected.

Selection of textile materials for acoustic applications is quite important. Although extensive research has been reported on sound related properties, yet there is no rule of thumb to select any suitable fibre types for acoustic applications. Factors such as fibre type, fibre fineness, fibre diameter, fibre blending and fibre surface area directly contribute to such selection [9]. Our major intention is towards the blending percentage which decides the composition. It has been proved that the acoustic properties can be altered by changing the ratio of any component of fibre in the total fibre. Thus the composition becomes significant.

From the literature, three major methods have been identified which can be used for this particular experiment. The first is the impedance tube method is relatively simple and small. It was first developed to find the velocity of sound in gases. The tube is made from rigid transparent or opaque materials to confine the sound within the tube along one direction towards the direction of propagation [10]. The impedance tube method uses two approaches, namely standing wave ratio and transfer function [11]. Second, the reverberation chamber, which is an acoustic laboratory, one of the most widely used method for determining the sound absorption coefficient of any noise-reducing device or material [12]. To specify a measurement method for the absorption coefficient of acoustic materials used for treating ceiling or walls, there must be well-defined assay conditions in the chamber. The reverberation chamber has been a matter of research for some time now. Usually, large reverberation chambers are built, but a general procedure can be applied to a smaller chamber as well. The volume rather than the shape of the reverberation chamber is important [13]. Third, the impulse method which is mainly used for the frequencies in the ultrasonic region of 4 kHz to 40 kHz with few major assumptions [14].

There are several applications where fibres and fabrics are incorporated to noise reduction purposes. Fabrics with this specialty are used in theatre curtains, room partitions, window curtains and drapery applications. Greater application of fabrics in the automotive industry provided vast advantages in terms of noise reduction [15]. Large auditoriums are inhibited by some sort of textile material to eliminate the impacts of sound reflection. In home textiles the sound proof materials made of textiles are very commonly used [16].

Therefore, the overall goal of this investigation is to analyse the sound related properties such as sound reflection, transmission and absorption of Polyester / Cotton blended fabrics with different physical parameters, namely thickness, composition and areal density.

2. Methodology

2.1 Development of Apparatus

The impedance tube is developed with the intention of measuring all three sound-related properties, namely absorption, transmission and reflection in a single step. In order to perform such experiments, there are certain calculations that need to be done for the device prior to designing.

The tube is an important functional as well as structural part of this apparatus. Based on the analysis, to keep the cost minimum, the standard PVC plastic pipes available in various diameters and wall thickness combinations were studied. In order to have an efficient use of frequency range, the diameter of 90 mm PVC was selected. The larger diameter will be having a frequency within a short range [17]. The next stage of designing was the determination of the length of the tube. In order to determine the proper working length the following relationship was employed. The length of the tube was selected as 75 cm.

$$L > 3d \qquad \text{…. (1)}$$

Where L – Length of the tube

d – Diameter of the tube

In general, the tube should support the source at one end and support a specimen along with the sample holder at the opposite end. The specimen is mounted vertically in most cases. The target of the research was to measure the three aspects. To do that, a microphone was fixed on one end of the tube. The microphone which was fixed was capable to respond to pressure of the waves which were transmitted through the specimen. The output was connected to the laptop which was installed with suitable software.

The next stage was the determination of the way of mounting the specimen inside the tube. Using the energy conservation law, the specimen was planned to be mounted at 45° to the horizontal plane. This will make the task easier by measuring the reflection using another microphone which is

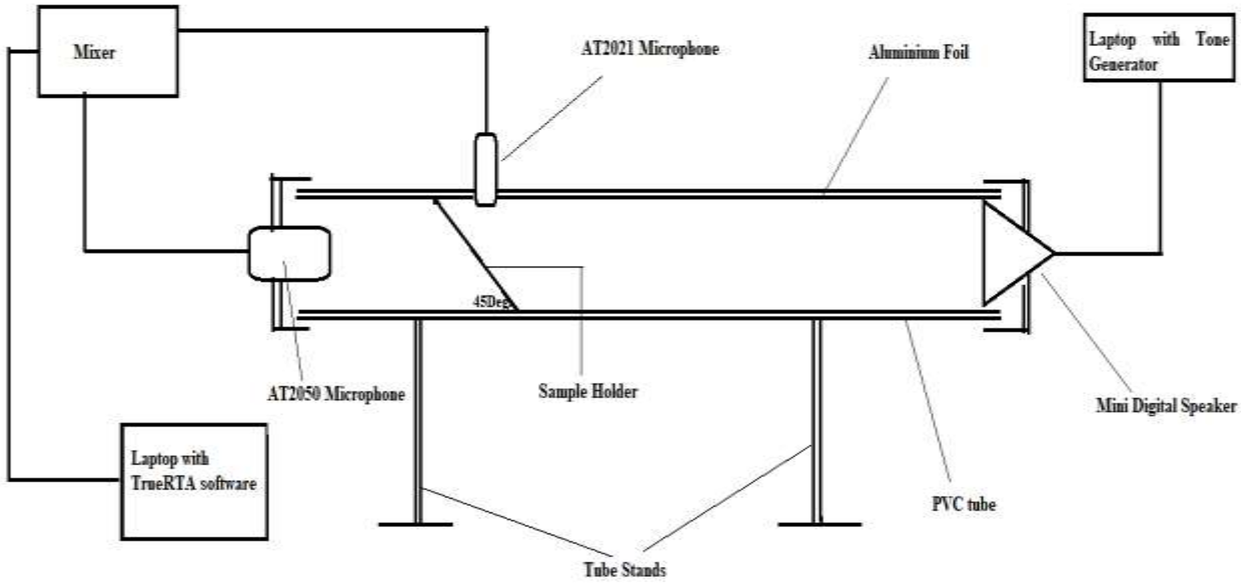

Figure 1 - Experiment Setup

only sensitive to cardioid polar patterns. So that, the reflected rays are captured and projected using another laptop which has the same software. After the proper selection of materials and length parameters, it is a must to determine the maximum and minimum working frequencies [18]. Since the devices were capable to function within the audible range, the following theoretical approach was adopted to identify the cut-off frequency and minimum frequency. The cut-off frequency is the upper most working frequency.

$$f_u = \frac{KC}{d} \quad \text{.... (2)}$$

Where f_u – Cut-off frequency
K – Proportion Constant (normally 0.586)
C – Speed of the sound (Assumed 340×10^3 mm/s)

From the above relationship the Upper working frequency was determined as 2500Hz. The distance between the sample and microphone should be greater than half of the tube diameter for the flat sample surface [19]. Spacing between the microphone can be calculated by the formula given.

$$S \ll \frac{C}{f_u} \quad \text{.... (3)}$$

Where S – Spacing
C – Speed of Sound
f_u – Upper most working frequency

It is only applicable for the two-microphone method mentioned in the literature. But in this case, spacing values were calculated to determine the minimum frequency that can be employed. To evaluate lowest frequency response of the system the following systematic equation can be used.

$$f_1 = \frac{0.1\,C}{2S} \quad \text{.... (4)}$$

Where, f_1 is the lowest frequency of the system.

Based on this, the lowest frequency was calculated as 200Hz. Figure 1 shows the technical diagram of the set up.

Once the required calculations were made, the positions for the microphones were fixed using melt drilling.

2.2 Selection of components for the acoustic impedance tube

a. Microphones

Two types of microphones were selected with different polar patterns. Both microphones were sensitive to a full frequency range of 20Hz to 20 kHz. The microphone with three switchable polar patterns was used to measure the transmitted waves while the one with only cardioid polar pattern was preferred for reflection measurements.

b. Speaker

For the experiments a Multimedia Mini Speaker with a frequency response of 30 Hz to 20 kHz and sensitivity of 80dB with 4ohms impedance was used.

c. Tone Generator

Aiglon tone generator, which was developed by 2007 Aiglon software company, was preferred to be used for this particular study as it has the ability to produce different waves such as sine, square, triangle and saw tooth on two frequency channels.

d. Frequency Analyzer

Among the various software available, TrueRTA Real Time Spectrum analyzer was chosen. True Audio's TrueRTA is a collection of real-time software-based instruments for testing and evaluating audio systems using a PC with basic sound input/output capability. The instruments found in TrueRTA include a low distortion signal generator, a digital level meter, a crest factor meter, a dual trace oscilloscope and a high-resolution real time analyzer. This provides uncountable advantages in audio measurements.

2.3 Sample Preparation

The tube diameter was determined as 90 mm and the sample size also decided as 90 mm. The seven sets of samples were prepared as depicted in Table 1.

Random stitches were used to combine the fabric layers one above the other. Each sample was kept under the pressure device prior to experimentation in order to eliminate the impact of air traps in the reading.

Moreover the sample size was reduced further using the Aluminium foil which was used to insulate the inside of the tube. The reason behind this is to avoid the instability and the fluctuations in the data collection.

Table 1 – Sample specification

Specimen	Composition	Areal Density (gsm)	Structure
A	100 % Cotton	105.65	Plain Weave
B	80/20 Polyester / Cotton	105.85	Plain Weave
C	65/35 Polyester / Cotton	106.00	Plain Weave
D	60/40 Polyester / Cotton	105.75	Plain Weave
E	50/50 Polyester / Cotton	113.74	Plain Weave
F	50/50 Polyester / Cotton	128.43	Plain Weave
G	100 % Polyester	105.23	Plain Weave

2.4 Processing of Data

Based on the knowledge gained through the literature review some equations were identified to be used for the calculations of absorption coefficient, reflection coefficient and transmission coefficient.

According to the energy conservation principle, it is possible to define the following equation.

$$\frac{I_r}{I} + \frac{I_t}{I} + \frac{I_a}{I} = 1 \quad \text{.... (5)}$$

Where, I_r – Reflected ray intensity

I_t – Transmitted ray intensity

I_a – Absorbed ray intensity

The standing wave [17] can be determined by,

$$s = \frac{|P_{max}|}{|P_{min}|} \quad \text{.... (6)}$$

Where, s – standing wave ratio

P_{max} and P_{min} – Maximum and Sound pressures at a selected frequency

From the above relationship, the sound absorption coefficient for a plane wave [18] can be established as,

$$\alpha = 1 - \left(\frac{s-1}{s+1}\right)^2 \quad . \quad \text{.... (7)}$$

And the sound reflection coefficient[18] as,

$$r = \left|\frac{s-1}{s+1}\right| \quad \text{.... (8)}$$

Finally the sound transmission coefficient can be found using the equation (5).

From the developed method and device, the maximum and minimum pressures were measured at each frequency level and the readings were converted into a readable format.

3. Results and Discussion

3.1 Influence of Thickness on sound related properties

All the layers continue to increase their absorption coefficient with increasing frequency. For all the layers there is a sudden rise in the pattern during the frequency range between 1000-1600 Hz which coincides with the previous researches.

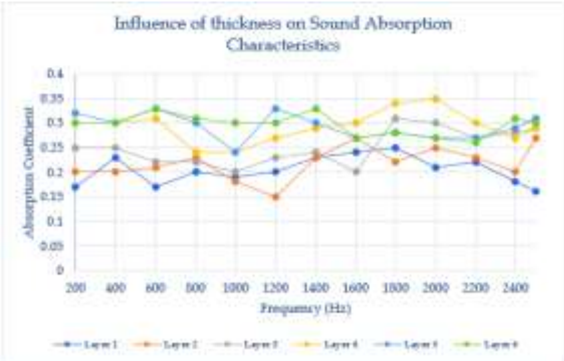

Figure 2- Influence of Thickness on Sound Absorption Characteristics

The absorption bandwidth can also be seen to be significantly improved towards lower frequencies of the test samples. The thicker the absorber, the more the low frequency components can be absorbed. The thickness which is attained by layering technique provides more surface area for the sound energy to get absorbed. As a result certain frequencies get absorbed by the samples when the number of layers is increased. In case of increasing the thickness, the sound transmission path is increased, resulting in frictional losses and damped sound energy. However, the sound absorption coefficient no longer increases after the thickness reaches a critical value. Therefore the thickness should be selected based on limiting factor and the behaviour.

Similar to the behaviour of light, when the number of layers is increased the reflection of sound is also increased up to a certain limit. As the number of layers is increased and the sound rays hit the surface, the direction of the rays is altered. The reflection coefficient is increased for a particular sample from lower frequency to higher. The thicker the material, lower frequencies can be reflected more. This reflection coefficient normally lies within the range of 0.28 to 0.48 for all the samples. The peak values occur at around 1600 Hz with Coefficient of 0.48 for the six layered sample while the lowest is at around 1800 Hz with coefficient of 0.28 for the single layered sample.

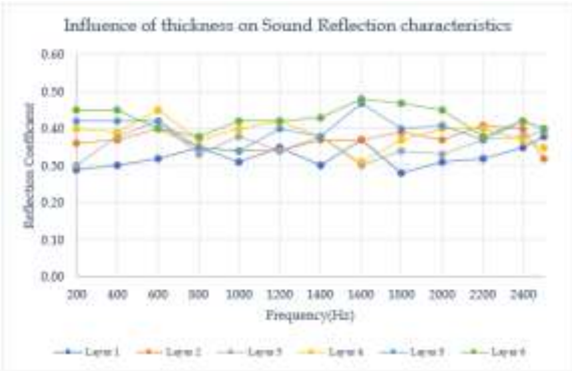

Figure 3- Influence of Thickness on Sound Reflection Characteristics

The transmission characteristics are opposite to absorption and reflection. This is due to the air pores that allow sound to travel through them when the number of layers is reduced. Therefore the transmission coefficient decreases when the number of layers is increased. At the same time this decreases with the increasing frequency as well. Sound transmission mainly occurs when the impedance of a material and air are similar. This is due to the impact of resonance as well. The transmission coefficient values are between the ranges of 0.24 to 0.56.

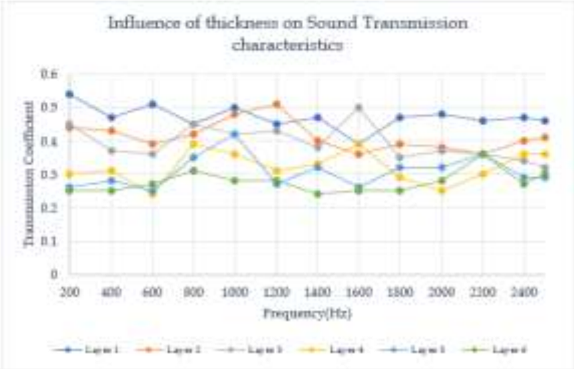

Figure 4- Influence of Thickness on Sound Transmission Characteristics

3.2. Influence of Composition on sound related properties

The results show that 100% polyester has the highest sound absorption. The 100% cotton fabric has the second highest sound absorption and all the other compositions have lower sound absorption than these 2 samples. The third highest sound absorption is for 50/50 Cotton polyester blended fabrics.

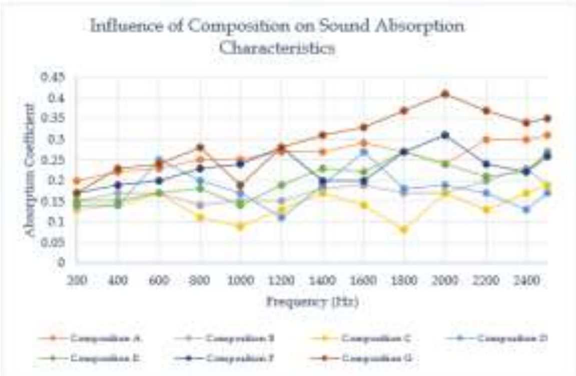

Figure 5- Influence of Composition on Sound Absorption Characteristics

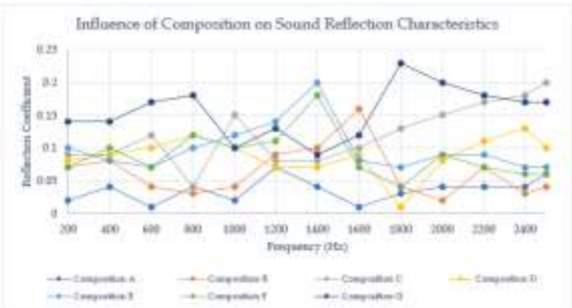

Figure 6- Influence of Composition on Sound Reflection Characteristics

100% cotton fabrics have the highest sound reflection coefficient and 100% polyester fabrics have lowest sound reflection coefficient.

The other samples have reflection coefficient in between those two values. For sound reflection surface properties of fibres have significant influence. If there are more polyester fibres it shows high reflection coefficient due to smooth fibre surface.

Sound transmission coefficient is very much lower in 100% polyester fabrics. All the others have almost identical transmission values with very small variations. In middle frequencies 50/50 polyester cotton blended fabrics have lowest transmission values.

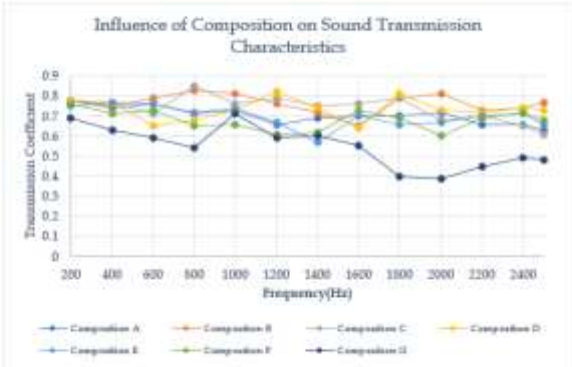

Figure 7- Influence of Composition on Sound Transmission Characteristics

3.3. Influence of Areal density on sound related properties

For both samples there is a sudden rise in the pattern during the frequency range between 1000-1600 Hz which coincides with the previous researches.

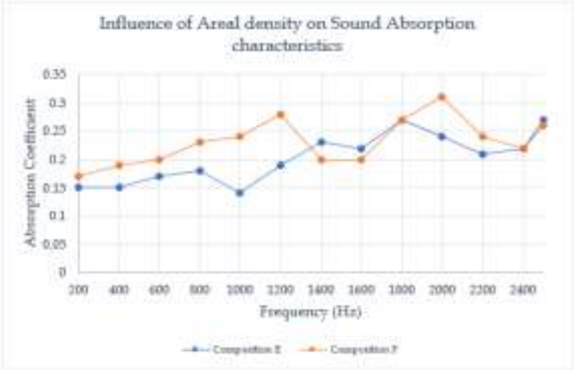

Figure 8- Influence of Areal Density on Sound Absorption Characteristics

The results show that a sound wave at high frequency or low frequency is absorbed more in dense fabrics. Higher density leads to a higher number of fibres per unit area. So it higher the frictional contact and energy loss becomes greater. Fabric density affects the sound absorption properties of woven fabrics positively. Sound absorption coefficients at frequencies of 1400 and 1800 Hz are small and almost identical.

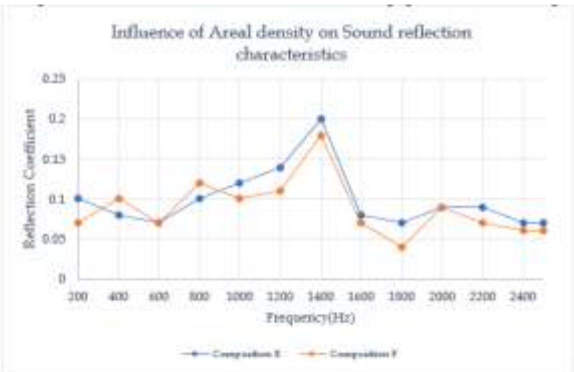

Figure 9- Influence of Areal Density on Sound Reflection Characteristics

When compared with low dense fabric, sound reflection coefficient of denser fabric has lower value in high frequencies and greater value in low frequencies. When there are more fibres in the fabric surface air flow resistivity increases. As a result fabric tends to reflect sound more than absorbing or transmission in denser fabrics in low frequencies. But in high frequencies more amount of waves are absorbed than reflection or transmission. So the reflection coefficient is low in denser fabrics at high frequencies.

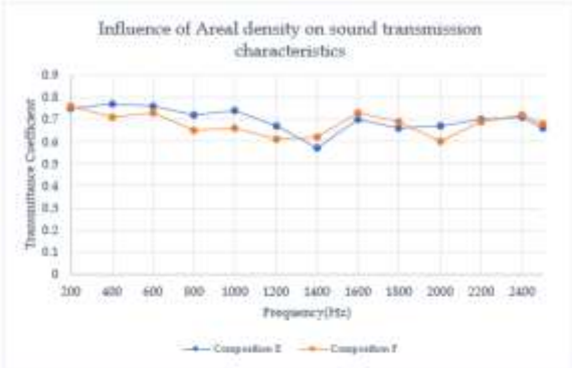

Figure 10- Influence of Composition on Sound Transmission Characteristics

Sound transmission decreases by a small amount with the increase of fabric density. The reason for this is when the fabric density increases air flow resistance of the fabric is increases. If it is a less dense fabric more sound waves can penetrate through it without absorbing or reflecting. According to the results the effect of density on sound transmission coefficient is less.

There are some unexpected drops in the pattern which is due to the influence of several factors such as external noise, inhibited noise of the device itself and atmospheric conditions.

4. Conclusion

The influence of physical parameters such as thickness, composition and areal density on sound-related properties like absorption, reflection and transmission of the selected Polyester / Cotton blended fabrics, using the newly fabricated experimental setup was assessed. For this particular study, the polyester /cotton blended fabrics were taken in five different compositions with the same structure and with almost equal gsm values. The analyzing equipment was developed with the prior study on impedance tube behavior. The expense for this developed equipment is quite low and it has effective functionality.

The test results were collected under standard atmospheric conditions and required number of readings was taken to prove the precision and accuracy. The results showed that the selected properties have some considerable impact on sound related properties. Based on the analytical values, the manufacturers can choose the appropriate composition of the analysed fabrics for their selected applications, which might provide them the advantage in the cost factor.

There are some drawbacks in the system and the readings as well. The readings fully depended on the person who is performing the experiment. The time of conducting the tests considerably affected the nature of the fabrics analysed. Moreover, there were some external noises that cannot be avoided in the data collection. Even though as a comparison study, this is effective for the selection of fabrics for small scale noise reduction applications.

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