An Investigations of Sound Absorbance Properties of Weft Knitted Spacer Fabrics

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(Received 2 November 2013; revised 22 March 2014; accepted 30 April 2014)

Nonwoven fabrics have been used for many years in different technical applications; they have particularly been used as isolation materials in vehicles in order to reduce the noise heard within them, and they. They have achieved great popularity due to low production cost and good absorbance. However, the fabrics produced by making use of the nonwoven technique have some disadvantages including low resistance, low abrasion strength, poor aesthetic appearance and thickness. In order to eliminate these disadvantages, recent studies have reported that knitted fabrics could be an alternative to nonwoven fabrics. Various studies have focused on the impact on sound absorbance that the thickness and surface structure of knitted fabrics have. In this study, a number of knitted spacer fabrics, which had five different connection angles, were manufactured by using a plain knitting machine. The sound transmission loss levels of the developed fabrics were tested and analysed by Brüel and Kjaer tube instruments. At the end of the examinations, the sound absorbance behaviors at different frequencies were demonstrated in graphics based on the type of knitting. It was determined in the study that three factors have a major impact on the sound absorbance behaviour; thickness of fabric, micro porosity between fabric surfaces and yarn linear density in the interconnection of the fabrics.

1. INTRODUCTION

In humans, the audible range of sound frequencies is usually 20 Hz to 20.000 Hz. For a sound to be heard, the sound intensity should reach a certain level. Human sounds usually cover the frequencies of 250-500-1000-2000 Hz. If these audio waves appear in a random spectrum or, in other words, if they are undesired sounds, they are called ”noise”.

In parallel to technological advancements, the development of metropolitan regions, and the lightening of structures, environmental impacts that affect humans are also on the rise. One of these notable impacts is the sound pollution, or environmental noise, which is irritating, undesirable, and uncomfortable. In addition to the discomfort that it causes, it also has negative impacts on the psychology, physiology, and performance of humans. Besides, noise can result in behavioral disorders, decline in working performance, hearing loss, tinnitus and psychological diseases.

In the urbanized and mobilized life style of today's world, the time spent within cars has increased. Thus, sound insulation has gained an increasing importance in the automobile industry for both the comfort of driver and the health of passenger. With the increase in the power of engines used in the automobile industry, low-frequency sound within the car has appeared to be a problematic area that needs to be resolved. Although this frequency range is generally below 4000 Hz, sounds in the range of 100–1000 Hz cause passengers to feel tired.[1]

If a sound encounters an obstacle while propagating in a medium, it behaves in three different manners as in the case of other physical phenomena. A certain part of the sound reflects from the obstacle, and the obstacle absorbs a certain amount of it while the rest passes through the obstacle. Therefore, each material has a specific absorbance coefficient. As textile materials are porous structures, they allow sound absorbance. Thus, they are used in a wide range of applications including acoustic panels used in workplaces, insulation materials for automobiles and furnishing fabrics in the concert halls.[3,4]

In industrial applications, fibreglass, foam, mineral fibres and their composite materials are used for sound insulation.

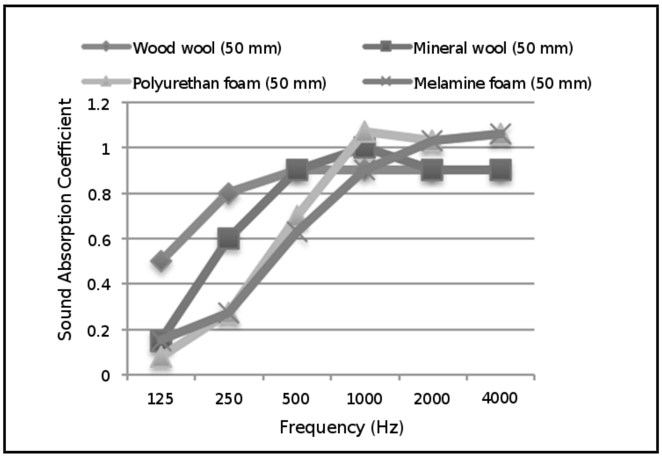

Figure 1. Sound Absorbance Behaviours of Certain Materials.[2]

Even though these materials have good heat and sound insulation properties, they have negative impacts in terms of environmental pollution and human health.

In the transportation sector, manufacturers have used three main methods for sound control and sound reduction within the car. These are the reduction of sound and vibration sources, establishing anti-sound barriers between the passenger and the sound source, and using absorbent materials for sound propagation inside and outside the car.[2]

Nonwoven textile fabrics are commonly used in automobiles for sound insulation, as they are cost effective. However, it is less likely to manufacture nonwoven textile products as preformed or in the desired form. On the other hand, knitted fabrics have an aesthetic appearance, and they provide the opportunity to be manufactured in the desired form. The sound insulation capacity of single-plate knitted fabrics is poor.[1] Thus, it is more appropriate to use double plate special patterned fabrics in the knitted fabrics for sound insulation.

Two different conclusions were drawn at the end of the measurements of the sound absorbance coefficients of the different spacer fabrics, which were manufactured out of 972 dtex yarn with double polyamide coating in the exterior face and elas-

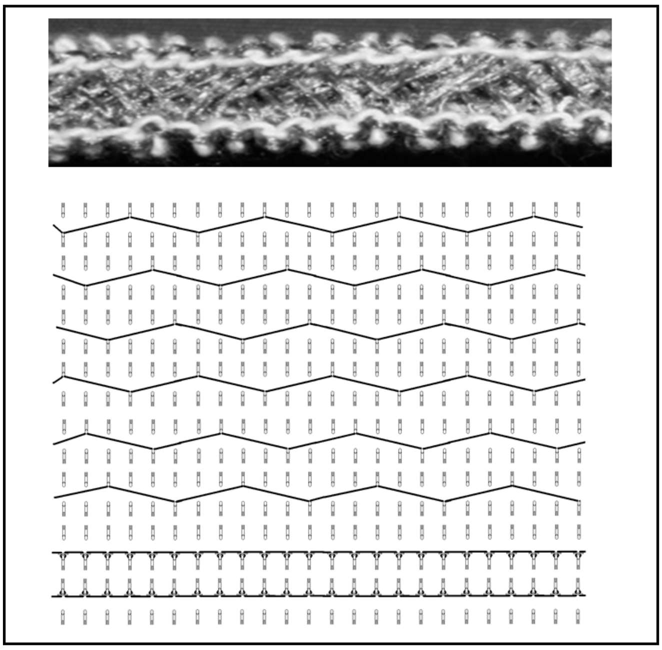

Figure 2. Technical drawings and photographs of sample fabric knits (SF-A).

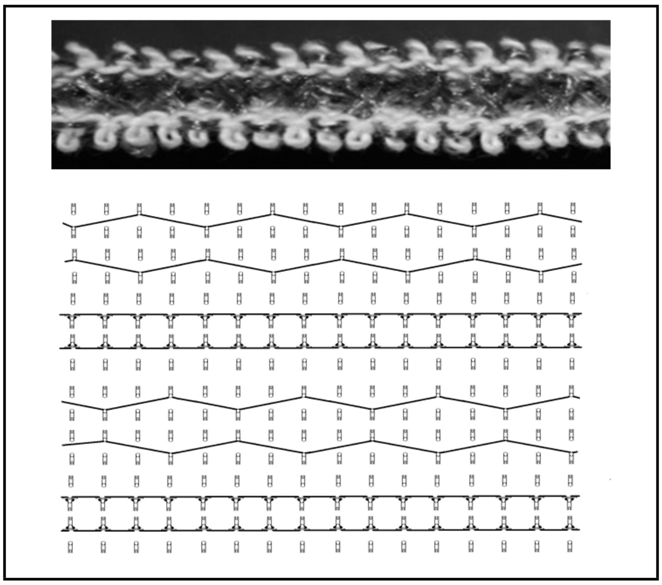

Figure 3. Technical drawings and photographs of sample fabric knits (SF-B).

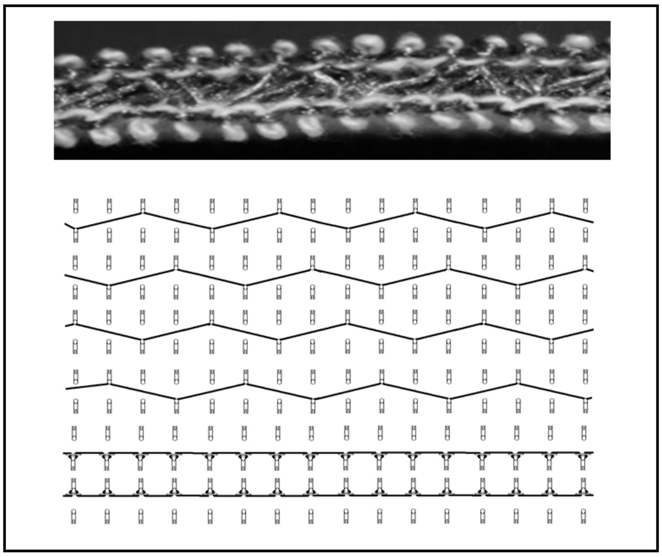

Figure 4. Technical drawings and photographs of sample fabric knits (SF-C).

tomeric material in the inner face both at the front and reverse sides and out of 430 dtex and 380 dtex polyester yarns in the interconnections. The first conclusion was that the sound absorbance coefficient increased in direct proportion to the thickness of the fabric. Secondly, it was detected that the sound absorbance coefficient increased with the decline of spaces in the front and reverse sides of the fabrics.[5]

200 dtex tencel, 167 dtex textured polyester, and 972 dtex textured polyester yarns were used in the front and reverse sides of six different spacer fabric samples. In the inter connections, 167 dtex textured polyester yarn was used. It was determined that the sound absorbance capacity tended to decrease as a result of the decrease in the surface porosity and increase in the surface density. It was also concluded that the fabric surface density was more dominant than the fabric thickness in sound absorbance.[6]

It was determined that in single jersey fabrics manufactured with polyester yarns at different loop densities, the sound absorbance capacity of the fabric with a larger space in the surface was higher than that of the fabric with a smaller space in the surface.[1] It was observed that the increases in the spaces and the thickness in the three different spacer fabrics, manufactured by using cotton yarn in the front and reverse sides and polyester yarn in the inter connections, occurred in direct proportion to the sound absorbance.[4]

2. MATERIALS

2.1. Yarn Properties

In this research, 100% Cotton Ne5/1 yarn was used in the front and reverse sides of the sample fabrics. 700 denier 100% acrylic continuous filament yarns were used in the inter connections. Prior to producing the spacer fabric structures, the fibres were conditioned for 48 h in 65% relative humidity and 20°C temperature. The physical properties of five different spacer fabrics used in the research are given in Table 1.

2.2. Fabric Constructions

The STOLL CMS (420 model no. E7) plain knitting machine was employed during the production of the fabric structures. The spacer knits with five different inter connections were developed, and the technical drawings and the surface appearances of the patterns produced are shown in Figs. 2–6.

2.3. Measuring of Sound Absorptions

2.3.1. Theory

The use of impedance tubes for measuring the TL values of different materials has been developed in recent years. The technique was initially introduced to measure the TL of muffler systems but since has been modified for TL measurement of different materials. The theoretical principle behind this is based on the transfer matrix method.

The complex amplitudes of the sound pressure (A–D) are calculated by measuring complex pressures (p1–p2) as follows:

$$A = \frac{-i}{2} x \frac{p_1 - p_2 e^{-ik\sigma x_1}}{\sin k\sigma x_1} e^{-ik\sigma x_2}; \quad (1)$$

$$B = \frac{i}{2} x \frac{p_1 - p_2 e^{ik\sigma x_1}}{\sin k\sigma x_1} e^{ik\sigma x_2}; \quad (1a)$$

$$C = \frac{i}{2} x \frac{p_4 - p_3 e^{-k\sigma x_4}}{\sin k\sigma x_4} e^{ik\sigma x_3}; \quad (1b)$$

Table 1. Properties of fabric construction.

Fabric Code	Course (cm)	Wale (cm)	Area Density (g/m^2)	Fabric Thickness (mm)	Connecting Yarn per Course	Connecting Yarn Angle
SF-A	5	4	1159	6,24	1:6	10
SF-B	6	4	865	5,50	1:2	15
SF-C	6	4	998	5,40	1:4	15
SF-D	5	4	1040	5,77	1:2	45
SF-E	6	4	830	5,31	1:2	10

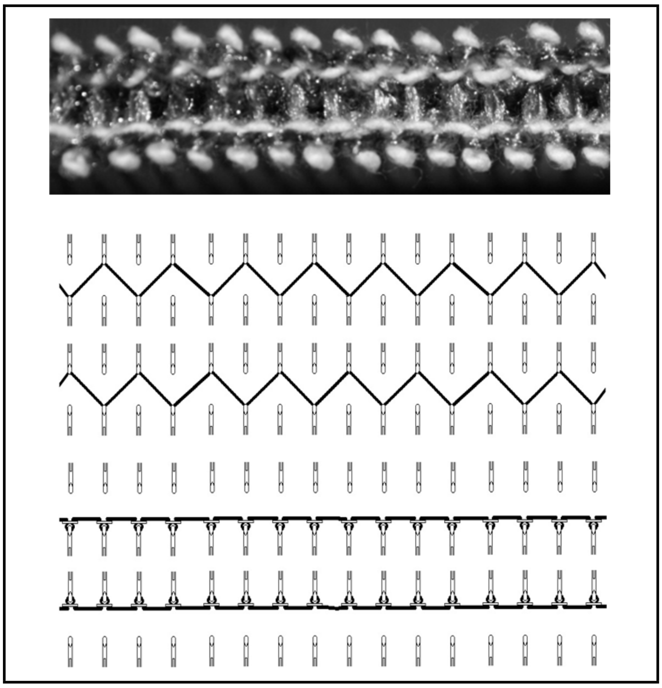

Figure 5. Technical drawings and photographs of sample fabric knits (SF-D).

$$D = \frac{-i}{2} x \frac{p_4 - p_2 e^{ik\sigma x_4}}{\sin k\sigma x_4} e^{-ik\sigma x_3}; \quad (1c)$$

Where,

$$\sigma x_1 = |x_1 - x_2|; \quad (2)$$

$$\sigma x_2 = |x_2|; \quad (2a)$$

$$\sigma x_3 = x_3; \quad (2b)$$

$$\sigma x_4 = x_4 - x_3. \quad (2c)$$

The transfer matrix is defined as the matrix that relates the above complex amplitudes of the sound pressures. Therefore,

$$\begin{Bmatrix} A \\ B \end{Bmatrix} = \begin{bmatrix} \alpha & \beta \\ \gamma & \sigma \end{bmatrix} \begin{Bmatrix} C \\ D \end{Bmatrix}. \quad (3)$$

The TL value is in fact:

$$TL = 20 \log |\alpha|. \quad (4)$$

There are two different techniques to obtain α from the measured sound pressures and then determining the TL values: the anechoic termination method and the two-load.[2–6] In this paper, a method is introduced, which combines the above techniques: the close rigid termination, and the sound absorbing termination (a thick piece of rock wool against a rigid wall) (Fig. 4). The TL value is calculated using:

$$TL = 20 \log \left| \frac{A_a D_b - A b D_a}{C_a D_b - C_b D_a} \right|; \quad (5)$$

The subscripts a and b here denote the close rigid and absorbing termination, respectively.

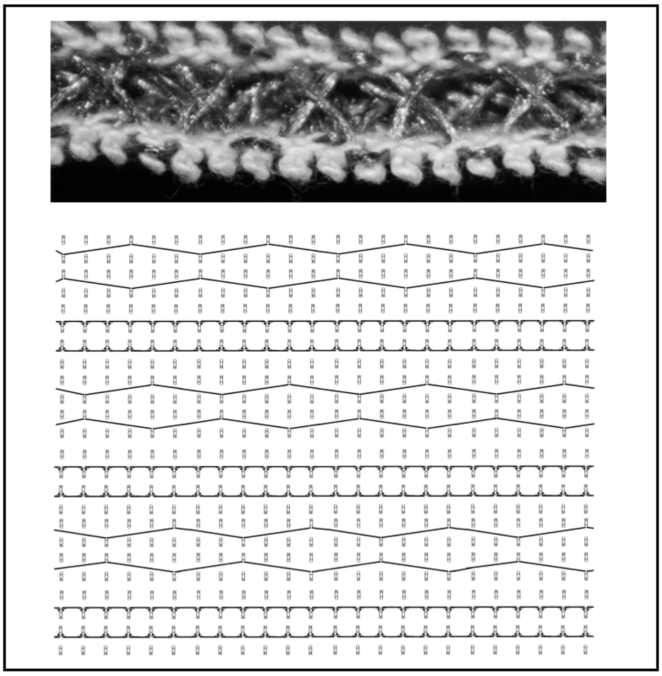

Figure 6. Technical drawings and photographs of sample fabric knits (SF-E).

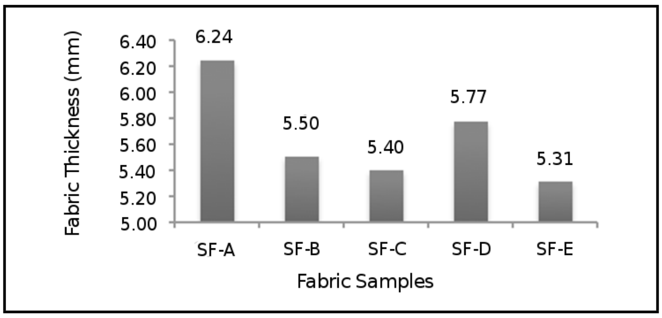

Figure 7. Thickness of fabrics.

2.3.2. Method

The material measurements are based on the two-microphone transfer-function method according to ISO 10534–2 and ASTM E1050–98 international standards, which is for the horizontal mounting of orientation-sensitive materials and the simulation of measurements on hanging ceilings, wall mountable. The testing apparatus is a part of a complete acoustic material testing system, featuring Brüel& Kjær PULSE^{TM} system (Fig. 9).[7]

2.3.3. Impedance Tube; the Two-Microphone Transfer-Function Method

A small-tube setup is used to measure the parameters for the frequency range of 50–6400 Hz. A small impedance tube kit from Brüel&Kjær Type 4206 consists of a 29 mm diameter tube (small tube) sample holder and an extension tube. A frequency-weighting unit is also provided, in which, types of weighting are selectable; high-pass for high frequency mea-

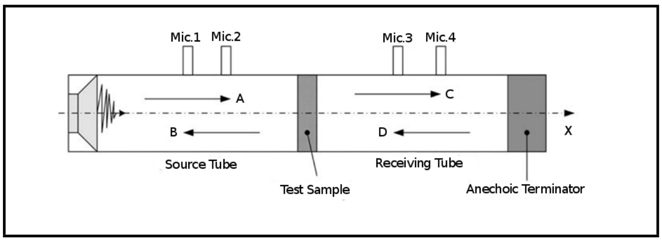

Figure 8. Schematic structure of the modified impedance tube apparatus used for the measurement of the TL values.

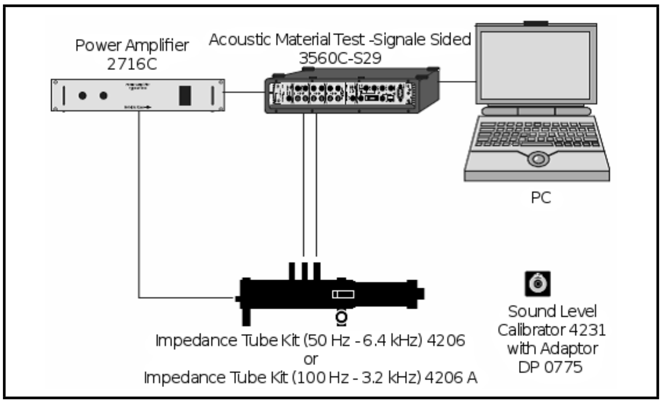

Figure 9. Test Setup.

surements in the small tube, linear for measurements in the large tube, and low-pass for extra measurement accuracy below 100 Hz. At one end of the impedance tube, a loudspeaker is mounted to act as a sound source. The testing material is placed at the other end of the tube for the testing of sound absorption properties (Fig. 10).[7]

2.3.4. Measurement Methodology and Material

A sound source is placed at one end of the impedance tube, and a sample of the material under testing is placed at the other end, mounted at a fixed distance from a rigid reflecting plate. A signal generator and an amplifier feed the loudspeaker with a broadband, stationary random noise: the sound waves propagate as plane waves in the tube, hit the sample, and are then reflected. Therefore, a standing-wave interference pattern results due to the superposition of waves travelling forward and backward inside the tube. Measuring the sound pressure at two fixed locations and calculating the complex transfer function using a two channel digital frequency analyzer, it is possible to determine the complex reflection coefficient, the sound absorption coefficient and the normal acoustic impedance of the material.[6,8] The usable frequency range depends on the diameter of the tube and the spacing between the microphone positions: with the small tube setup (diameter = 29 mm), it is possible to make measurements in the frequency range between 500 and 6400 Hz. This frequency range is fundamental

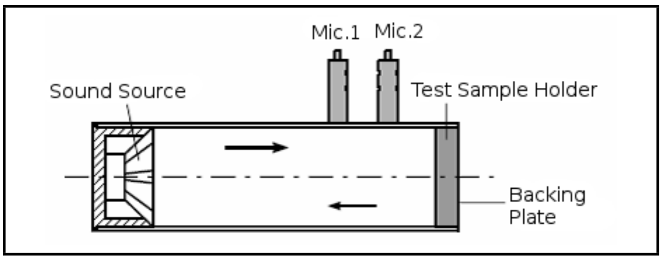

Figure 10. Impedance tube setup for the two-microphone transfer function method.

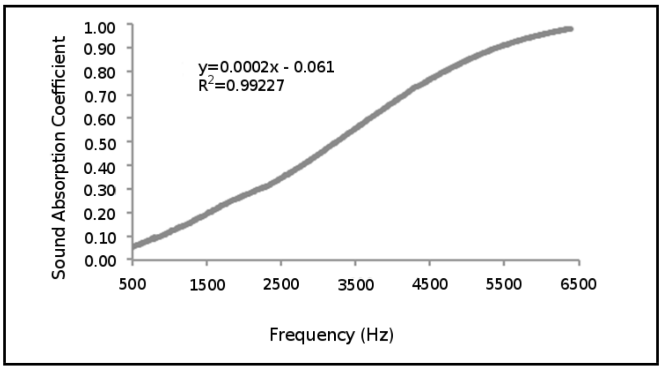

Figure 11. Acoustic absorption properties of SF-A.

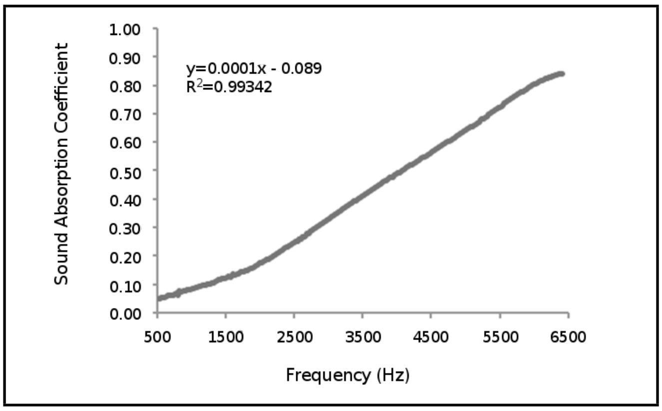

Figure 12. Acoustic absorption properties of SF-B.

with regards to traffic noise applications such as noise barriers (see for the traffic noise spectrum).[9]

3. RESULTS AND DISCUSSION

Figure 16 shows the test results related to the sound absorbance capacities of the spacer fabrics with different patterns. In the present study, the sound absorbance test was applied three times on each one of five spacer knitted structures produced with the connection types demonstrated in Fig. 1. A graphic was formed on the basis of arithmetic means of the data obtained as a result of these tests (Fig. 16). In the spacer fabric groups manufactured with all the pattern types, SF-A samples had the best sound absorbance behaviour depending on the knitting type, followed by SF-D samples. The lowest absorbance rate was detected in the SF-E sample.

When the graphic of the test results was examined, it was reported that, in all the samples, the sound absorbance coefficient increased in direct proportion to the frequency increase. In order to examine the pattern of behaviour of this increase, the separate sound absorbance graphics were drawn for all samples and Regression Analysis (R2) was made on these graphics. With the results of the Regression Analysis in Figs. 11–15, it can be seen that this increase behavior was high in all samples.

When the thickness values (Fig. 7) and the sound absorbance test results of the fabrics studied in the research were examined comparatively, a significant relationship was found between the thickness and the increase in the sound absorbance rate.

4. CONCLUSIONS

The results of this study indicate that the SF-A fabric had the highest sound absorption properties as compared to the devel-

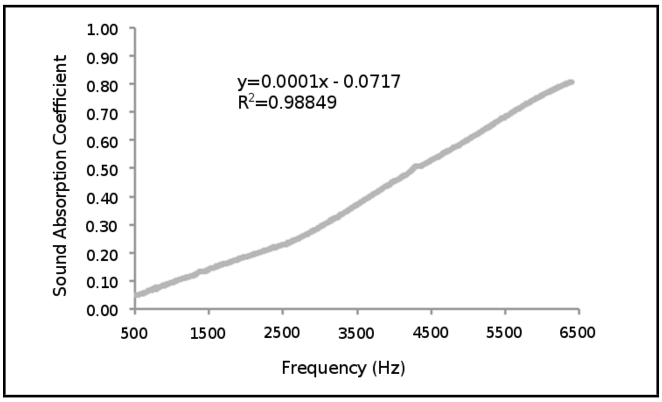

Figure 13. Acoustic absorption properties of SF-C.

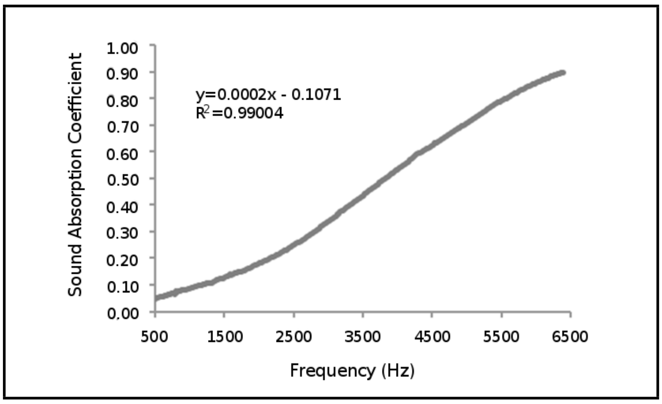

Figure 14. Acoustic absorption properties of SF-D.

oped fabrics in this study. On the other hand, it is also clearly seen that the SF-E fabric had the lowest sound absorption. Surprisingly, it was found that both SF-A and SF-E have the same technical drawings and yarn connecting angle; however, they have different fabric thicknesses. The thickness of the SF-A fabric has been found to be higher than the thickness of the SF-E fabric. A possible explanation for this is that the lower fabric thickness has caused a higher porous fabric structure, which directly affects the sound absorption properties of the fabrics. The thickness of the fabrics is related to fabric structures, the connecting yarn angle, and the yarn linear density. Another possible explanation for this is that the difference in the fabric's connecting yarn per course could also move in correlation with the yarn's linear density. These findings also suggest that when the connecting yarn angle increases, the thickness of the fabrics also increases. It can thus be suggested that the yarn connecting angle and the linear density of the yarn

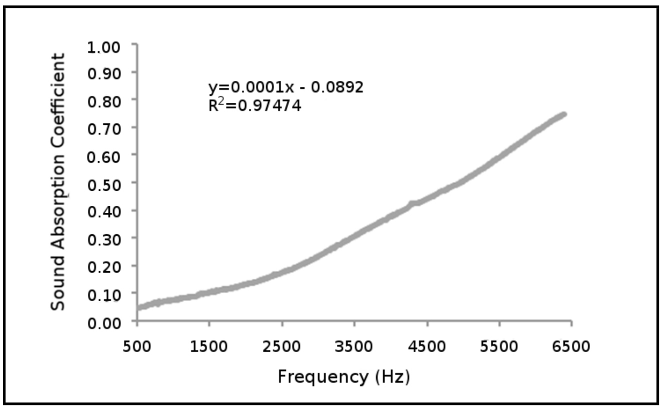

Figure 15. Acoustic absorption properties of SF-E.

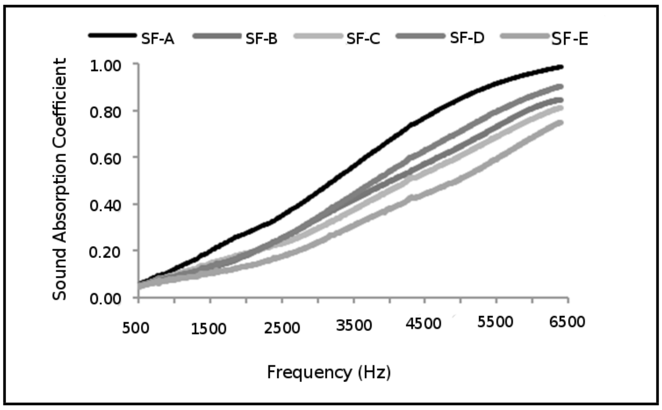

Figure 16. Acoustic absoption graphic of spacer knitted fabrics.

could be the major factors for the fabric thickness, and also a strong link may exist between the fabric thickness and the sound absorption.

The most obvious finding to emerge from this study is that a strong relationship between the thickness and the sound absorption exists. The observed increase in the sound absorption properties of the fabrics could be attributed to the increase in the fabric thickness and decrease the porous structure due to the connecting yarn angle and linear density of the yarn used. It is suggested that the association of these factors is investigated in future studies by making use of modelling software to estimate the sound absorption properties of fabrics.

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