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Sound Absorption of Multiple Layers of Nanofiber Webs and the Comparison of Measuring Methods for Sound Absorption Coefficients

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Abstract: Textile sound absorbents are getting more and more popular on the market as noise reduction is a major requirement for human comfort today. In this paper we focus on a new textile material for sound absorption, by investigating the acoustic characteristics of nanofibers. Through impedance tube method we measured the sound absorption coefficients of multiple layers of nanofiber webs and compared those with microfiber materials per fabric weight. We also examined the effect of layers of nanofiber webs on regularfiber knitted fabric on sound absorption. The test results showed that the sound absorption coefficients of nanofiber layers were superior that of microfiber fabrics in the frequency range 1000~4000 Hz. In this range, the sound absorption of nanofiber webs improved with numbers of layers. Also, adding nanofiber web plies to regularfiber fleece increased the sound absorption coefficient with 85 % at 4000 Hz. From our results we could observe differences in the sound absorption coefficients between two test methods, which are higher absorbance coefficients through the reverberation room method than impedance tube method.

Keywords: Noise reduction, Textile sound absorbents, Microfiber knits, Impedance tube method, Reverberation room method

Introduction

Noise, or unwanted sound, has become a growing problem to human health, as it can have several adverse health effects including hearing loss, sleep disturbance, and psychological harms [1,2]. One way to deal with this problem is to reduce noise using sound-absorbing materials. These materials have the ability to reduce noise via dampening or lessening sound wave reflections as sound energy is converted into heat energy [3]. Efficient sound absorbents should have the ability to prevent as many sound reflections as possible while also dissipating any unwanted sound entering the material. Porous materials can greatly improve sound absorption, especially, if the material contains open pores like channels. Sound enters through the channels and converts to heat as it moves through the material, thus efficiently dampening the sound [4,5].

Most of the porous sound-absorbing materials in use are fibrous and as such, textiles are widely used in noise abatement, but their efficiency is sometimes lacking. Noteworthy here is the complexity of textiles. The fabric, structure, densities, thickness and finishing methods etc. all influence the sound absorption property. Many researchers have given their efforts in researching the acoustic behavior of textile materials. Papers are also devoted to the establishment of guidelines based on numerical simulations, for optimal design of textile sound absorbents [6-9].

Within the field of technical textiles, nanofibers (fiber diameter less than 1 micrometer) have recently attracted great attention for sound absorption. The thin fiber diameter gives a high surface-to-volume ratio, which is an ideal property for producing a very lightweight and porous material [10,11].

From papers [5,12-15] it is suggested that when a layer of nanofibers is exposed to incident sound waves, the air friction inside the nanopores and scattering from the fibers lessen the sound. Furthermore, the layer acts as an acoustic resonance membrane. Certain frequencies bring the nanofibrous membrane into vibration which allows sound energy to convert into thermal energy, efficiently dampening the sound.

The development of nanofiber-based sound absorbents is promising and very much needed as there are increasingly higher demands on noise reduction in new products. So researchers [10,15] stress that more tests should be carried out on the sound absorption properties of nanofiber layers.

So far, no paper has been devoted to the comparison of the sound absorption properties of nanofibers to microfibers, neither has anyone presented the acoustic characteristics of composites of multiple nanofiber webs and regularfiber fabrics. In light of this, the present study intends to extend previous research [16] (in which we found that the sound absorption properties of microfiber fabrics were superior those of regularfiber fabrics), by comparing the acoustic properties of layers of nanofiber webs to microfiber fabrics. We will also investigate the effect of sheets of nanofiber webs on regularfiber fleece.

The acoustic properties have been compared through the sound absorption coefficients. This is the fraction of incident sound energy absorbed or otherwise not reflected from the surface [17]. The better a material dampens sound, the higher the material's sound absorption coefficients will be. There are two methods to measure the sound absorption coefficients, reverberation room and impedance tube. The reverberation room method provides the measure for random incidence absorption of large specimens. The impedance tube method

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measures the normal incidence absorption and requires only small specimens. Reverberation room results on carpets and on other non-textile dampening materials have been shown to be higher than impedance tube data [17-19]. To our knowledge, neither any comparison study has been made on microfiber fabrics nor on textiles mounted as a curtain in the reverberation room. Therefore, in the present work, we study any difference in sound absorption coefficients on microfiber fabrics between the two methods, with the test specimen installed as a curtain in the reverberation room.

Experimental

Nanofiber fabric was prepared trough an electrostatic process with melt spin polyamide fibers of nano diameters (fiber diameter: 800 nm). The fibers were heat-bonded to form nanofiber web (length: 40-50 m, width: 1 m, weight: 30 g/m^2).

In order to compare nanofiber webs with microfiber fabrics, several layers of nanofiber webs where plied together to fit the exact areal density of reference specimens of microfiber fabrics (Table 1). For the Suede fabric, six plies of nanofiber webs where put together and tested. The Queenscord fabric was compared with ten plies, Mesh was compared with eleven and the Terry fabric was compared with eighteen plies.

In order to analyze nanofibers as composite fibers, the effect of nanofiber layers on regularfiber knitted fabric was investigated by means of putting six layers of nanofiber webs on top of regularfiber fleece. Specification of microfiber and regularfiber fabrics is given in reference [16].

The acoustic properties, the sound absorption coefficient (SAC) and noise reduction coefficient (NRC), of these materials were measured. The NRC was calculated as the average value of the material's sound absorption coefficients at frequencies of 250, 500, 1000 and 2000 Hz.

A sound absorption coefficient test, (ASTM C-384) Impedance and Absorption of Acoustic Materials by Impedance Tube Method, was done to nanofiber webs and microfiber fabrics using two microphone impedance tubes with sample diameter of 30 mm, temperature 22 ^{o}C. The sound absorption test (ASTM C 423-02a) was done through a reverberation room method with experimental details given in the work [16].

Table 1. Characteristics of test specimens

Nanofiber fabric		Microfiber fabric*	
No. of layers	Areal density (g/m^2)	Structure	Areal density (g/m^2)
6	180	Suede	176
7	210	-	
-		Waffle	297
10	300	Queenscord	301
11	330	Mesh	335
18	540	Terry	532

*For fabric's structural characteristics in detail we refer to former research in our group [16].

Results and Discussion

Sound Absorption of Layers of Nanofiber Webs and Microfiber Fabrics with Similar Weight

In this section we will compare results from the examination of SACs on multiple layers of nanofiber webs and microfiber fabrics of similar weights. Table 2 shows SACs as a function of frequencies and NRC of the test specimens. The NRCs of the microfiber fabrics were in the range of 0.08~0.11. The NRCs of the multiple layers of nanofiber webs were in the range of 0.10~0.15, which is slightly higher than that of microfiber fabrics. At frequencies below 1000 Hz the SACs are quite low (<0.11), but at higher frequencies the SACs increased steadily for the nanofibers. Six and seven layers show no difference in SACs, but when comparing six to eighteen layers a very good agreement between increased areal density (more layers) and improved sound absorption, most significant around 2000 Hz, is found. So by adding layers of nanofiber webs more noise can be absorbed, since the conversion of sound energy to thermal energy increases,

Table 2. Sound absorption coefficients of test specimens

Material	1/3 Octave frequency band (Hz)						
	125	250	500	1000	2000	4000	NRC
Suede	0.01	0.07	0.08	0.07	0.14	0.32	0.09
Waffle	0.01	0.06	0.06	0.06	0.15	0.30	0.08
Queenscord	0.01	0.06	0.06	0.07	0.12	0.29	0.08
Mesh	0.03	0.07	0.07	0.07	0.12	0.33	0.08
Terry	0.03	0.06	0.08	0.10	0.18	0.42	0.11
6 nanofiber layers	0.02	0.06	0.07	0.08	0.17	0.48	0.10
7 nanofiber layers	0.02	0.06	0.07	0.08	0.17	0.49	0.10
10 nanofiber layers	0.01	0.05	0.07	0.08	0.24	0.48	0.11
11 nanofiber layers	0.00	0.06	0.07	0.09	0.32	0.57	0.14
18 nanofiber layers	0.01	0.06	0.07	0.11	0.34	0.55	0.15

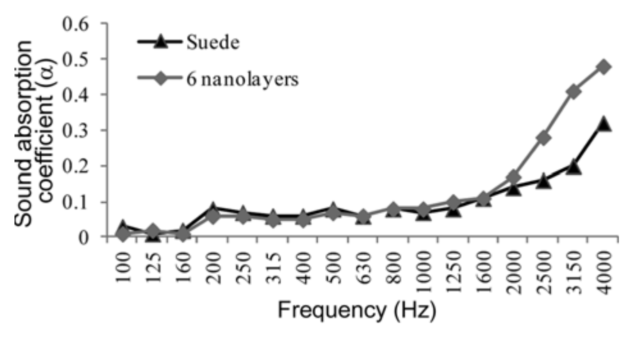

Figure 1. SACs of Suede microfiber fabric and nanofiber multiple layers of corresponding weight.

partly due to vibration of more layers.

In Figure 1 the SACs of Suede fabric are compared to six layers of nanofiber webs. The webs absorb sound with higher effectiveness, but in a quite narrow range, starting around 2000 Hz. Ten layers compared to Queenscord fabric absorb more efficiently for frequencies between 1000 and 4000 Hz (Figure 2). Also, eleven layers compared to Mesh absorb sound more efficiently in the frequency range 1000-4000 Hz (Figure 3) and eighteen layers compared to Terry feature similar improvement (Figure 4). The nanolayers are thought to absorb better in this frequency range thanks to the nanowebs working well on the resonance principle and by large specific surface so greater possibility for sound waves to interact with fibers in the structure.

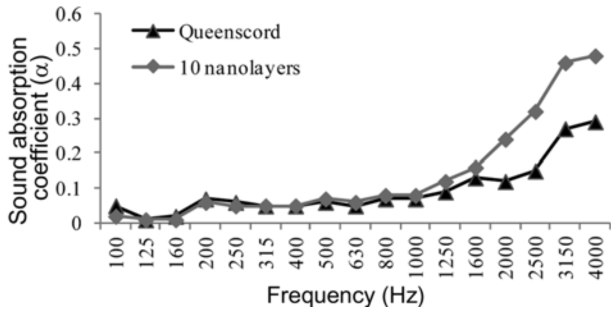

Figure 2. SACs of queenscord microfiber fabric and nanofiber multiple layers of corresponding weight.

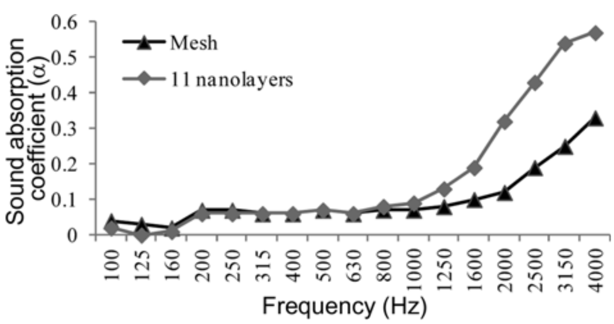

Figure 3. SACs of mesh microfiber fabric and nanofiber multiple layers of corresponding weight.

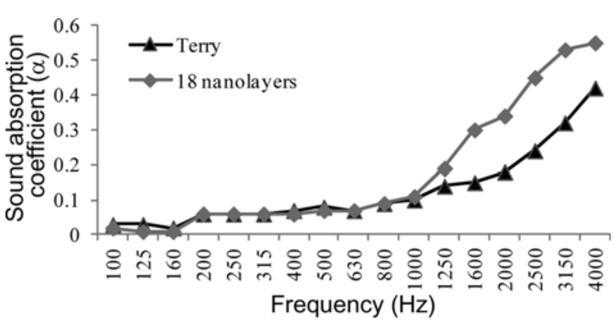

Figure 4. SACs of terry microfiber fabric and nanofiber multiple layers of corresponding weight.

Our earlier research on microfiber fabrics showed high surface area and fabric areal density to have more influence on sound absorption than fabric thickness or fabric weight [16]. The results from this experiment confirm the assumption that nanofiber will possess this property to a greater degree. By using nanofiber webs more efficient, lighter and thinner textile sound absorbents can be made comparing to those of microfiber fabrics.

The Effect of Nanofiber Layers on a Regularfiber Fabric on Sound Absorption

We also investigated the effect of nanofiber layers on a regularfiber knitted fabric on sound absorption. We found that six nanofiber sheets increased NRC from 0.128 to 0.178 and at the frequency 4000 Hz the SAC is increased by 85 % (Table 3). The contribution of the layers to better sound absorption in the frequency range 1000~4000 Hz can be seen in Figure 5. The feature of improved sound absorption at frequencies above 1000 Hz is in agreement with the acoustic properties of other highly porous composite materials, such as ultra-porous silica aerogel added in polyester nonwoven [20].

Our results prove that the sound-absorbing properties of regularfiber fabric can be enhanced by integration with

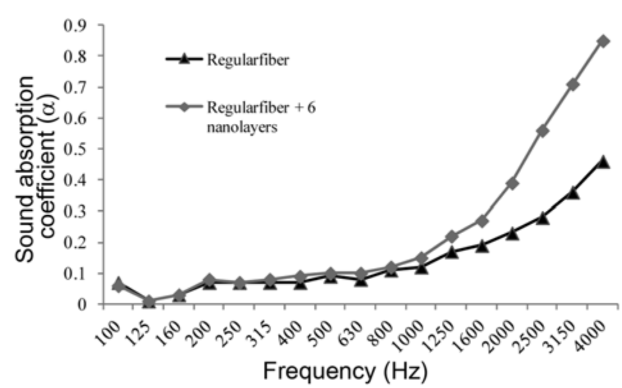

Figure 5. The effect of 6 nanofiber layers on regularfiber fleece on SACs.

Table 3. Effects of nanocomposite material on sound absorption coefficients

	1/3 Octave frequency band (Hz)						
	125	250	500	1000	2000	4000	NRC
Regularfiber fleece (1000 g/m^2)	0.01	0.07	0.09	0.12	0.23	0.46	0.128
6 nanolayers-Regularfiber fleece (1187 g/m^2)	0.01	0.07	0.1	0.15	0.39	0.85	0.178

layers of nanofiber webs. The human ear is very sensitive to sound with frequencies in the range 500~4000 Hz [21]. This is similar to the frequency range of improved sound absorption by nanofiber webs. Therefore, this material can be considered as a very good sound dampening material. To improve the SACs effectively it is, however, required to use several layers.

Comparison of Measuring Methods for Sound Absorption Coefficient

The measurements data of impedance tube method on microfiber test specimens were compared with the data obtained from reverberation room measurements on the same textile materials. We positioned the test specimens in a diagram according to their SACs data (Figures 6, 7). Our results indicate that the impedance tube method yields lower absorption coefficients than obtained in the reverberation room. Mesh was the only fabric with the same NRC (0.08) calculated through the two methods. This can be partly explained by the very open structure of Mesh fabric having low absorption for frequencies 250~2000 Hz in both methods. Instead, the Suede (0.19 and 0.09), queenscord (0.21 and 0.08), waffle (0.26 and 0.08) and terry (0.25 and 0.11) showed a considerable higher NRC in the reverberation room (Figure 8). From this, it could be interpreted that all over angle input in the reverberation room renders the possibility for more sound energy absorption and sound waves scattering in the textile compared to right angle input in the impedance tube method.

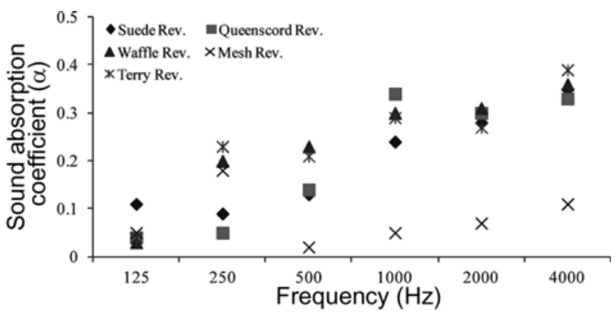

Figure 6. Diagram of SACs of microfiber test specimens according to the reverberation room method.

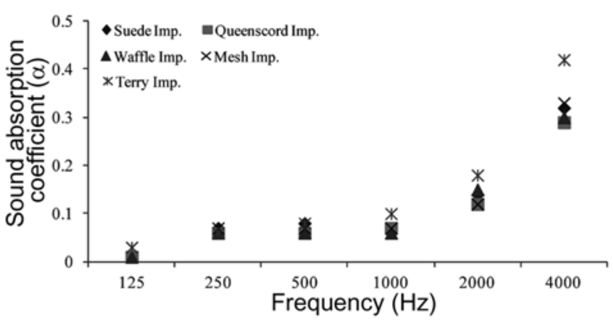

Figure 7. Diagram of SACs of microfiber test specimens according to the impedance tube method.

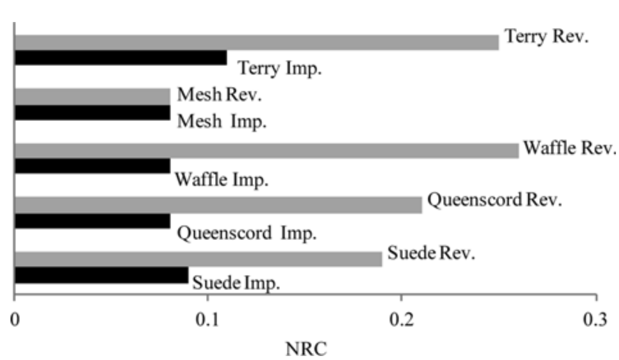

Figure 8. Comparison of NRCs between the impedance tube method and reverberation room method.

Conclusion

This paper reveals that sound absorption in the audible range can be better obtained by using multiple layers of nanofiber webs than microfiber fabrics of similar weights. It is proved that the interaction of sound waves with the large specific surface of nanofibers, air friction inside the nanopores and vibrations of the nanolayers constitute to the improved sound absorption.

The areal density of the layered nanofiber webs has an influence on the absorption properties. When comparing the SACs of six layers to eighteen layers, it is obvious that increased number of layers yields higher absorption. The improvement of SACs through the use of nanofiber webs is, however, only notable for frequencies 1000~4000 Hz.

Results also show that adding layers of nanofiber webs on regularfiber fleece improve the effectiveness of the sound-absorbing system. The latent quality of nanofibers to affect sound makes them ideal for use in, for example, automotive upholstery as a thin and light-weight sound reduction material. For future research, it is suggested to investigate how multiple layers of nanofiber webs best can be combined with other textile structures to fit various requirements.

The sound absorption coefficients are very important when considering the sound absorption performance of a material, but one need to be aware that the coefficients may vary according to test methods. This conclusion comes from noting the difference in the SAC's between our impedance tube method and reverberation room method.

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