2003 BELTWIDE COTTON CONFERENCES, NASHVILLE, TN – JANUARY 6-10

ACOUSTICAL PROPERTIES OF NONWOVEN FABRICS

E.A. Vaughn, R.J. Boston, and M. Tascan
Clemson University
Clemson, SC

Abstract

Nonwoven fabrics are ideal materials for use as acoustical insulation product because the fibers in the structure form void volumes, which entrap air. In fact a typical high loft nonwoven consists of about 10% fiber and 90% air for acrylic needled blanket, 2% fiber and 98% air for polyester auto air filter wrap, and 0.7% fiber and 99.3% air for fiberglass insulation material. The voids serve as reverberation chambers for acoustical insulation. The most important structural property for acoustical insulation is thickness of the nonwoven fabric. The thicker the material, the more possibility for the sound wave to touch the fibers in the structure. The other important parameter is the density of the fibers in the nonwoven material. The more fibers per unit volume at the same thickness, the greater the chance that the sound wave will interact with the fibers. Density also affects the geometry and the volume of the voids in the structure.

Acoustical properties of fabric materials are measured one of the two methods: the impedance tube (ASTM C 384-98) and the acoustic chamber method. Impedance tube method uses very small test samples for acoustical insulation measurements. Big reverberation rooms and big test samples are used on the acoustic chamber method. It is also very expensive to establish that kind of rooms. Because of these disadvantages of the test methods, a direct comparative acoustical properties measurement device has been developed and fabricated on the School of Materials Science & Engineering at Clemson University.

This presentation discusses the acoustical insulation measurement apparatus and some preliminary test results for a range of nonwoven fabric structures.

Introduction

Acoustical insulation is one of the most important properties of fiber products used in building and automotive applications. Noise in big cities disturbs people and makes them stressed. Therefore buildings in urban areas need efficient acoustical insulation material. Wind and road noise can exceed 100dB and cause pain to the human ear. Therefore transportation vehicles must incorporate an effective sound deadening material to block out specific noise frequencies.

Sound is a wave that travels along a path to a receiver. It can travel faster through water or steel. It consists vibrations of different frequencies. Frequency is one of two major parameters of sound. The other is the intensity or the loudness of sound. The frequency of sound in air does not change, but the intensity of sound decreases with increasing distance between the source and the receiver. The frequency range of human hearing is from 20 to 20,000Hz for a young healthy person. Humans are most sensitive at a frequency of about 4000Hz. The frequency range for human speech is between 125 and 8000Hz. The intensity of sound is measured in decibel (dB) units. The decibel is used to express loudness. A 0dB level is the threshold of hearing and a 130dB level is the threshold of pain. People are more sensitive to noises at higher frequencies. Hence a loud low frequency sound can be less annoying than a medium intensity high frequency sound. The threshold of human hearing is typically taken as a reference point for sound. A 1dB change is imperceptible, a 3dB change is barely perceptible, and a 6dB change is clearly distinct.

Textile materials can be used as both a sound absorber and an insulator. Fiber types used include fiberglass, rockwool, asbestos, cotton, wool, polyester, and polypropylene. Fiberglass, asbestos and rockwool were used all over the world until the 1960s, but because they were considered to be harmful, many countries banned their use. Wool has good insulation properties but it is very expensive compared to the synthetic materials. Cotton is used as sound insulator in buildings and automobiles in the form of shoddy. Cotton does not have to be high quality when it is used as a shoddy insulation product in shoddy. Most of cotton used for insulation is of low grade or is obtained from recycled yarn or fabric.

Recently, polyester and polypropylene have been used as a sound insulating material. Nonwoven fabrics are ideal materials for use as acoustical insulation product because the fibers in the structure form void volumes, which entrap air. In fact a typical high loft nonwoven consists of about 10% fiber and 90% air for acrylic needled blanket, 2% fiber and 98% air for polyester auto air filter wrap, and 0.7% fiber and 99.3% air for fiberglass insulation material. The voids in the fabric structure serve as reverberation chambers for acoustical insulation.

Important fiber properties for acoustical insulation are fiber diameter, fiber length, fiber shape, and fiber density. The different fiber shapes affect acoustical properties differently. For example, if hollow fibers are used instead of solid fibers, the amount of trapped air increases in the structure. Therefore insulation improves because trapped air is a very good insulator. Cotton fiber is also very good insulator.

The most effective structural property for acoustical insulation is the thickness of the nonwoven fabric. The thicker the material, the greater will be the possibility of the sound wave touching other fibers in the structure. Another important parameter is the density of the nonwoven material. The more fibers per unit volume at the same thickness, the greater the chance that a sound wave will interact with the fibers. Density also affects the geometry and the volume of the voids in the structure.

Acoustical properties of fabrics are generally measured by one of two methods: the impedance tube method (ASTM C 384-98) and the acoustic chamber method. The impedance tube method uses very small test samples for acoustical insulation measurements. This method is very useful for the samples that do not have big pores in the material. Textile materials have big pores in the structure.

Big reverberation rooms and big test samples are used for the acoustic chamber method. For example, a typical room is about $200m^3$ and the test sample is about $6m^2$. This room should also be in a very perfect shape in term of its walls and dimensions. Acoustic chamber rooms are very expensive to establish and maintain, but yield precise data.

Because of the disadvantages of these test methods, a direct comparative acoustical properties measurement device has been developed and fabricated at the School of Materials Science & Engineering at Clemson University. Our acoustical properties measurement device has the following features: it (1) is bench top or portable, (2) is simple to use, (3) provides rapid measurements, (4) is capable of analyzing a wide range of materials, (5) provides sample comparison to a reference or to a different sample, (6) uses an interchangeable sound source and detector for greater flexibility, (7) is capable of analyzing a wide bandwidth of complex frequencies, and (8) can be constructed at a reasonable cost.

We have named our apparatus the Clemson – Boston Differential Sound Insulation Tester.

Description of Apparatus & Testing Procedure

The need for determining and comparing the acoustical properties of textile materials quickly and cost effectively is obvious to researchers and manufacturers. Determining acoustic properties can be complex and expensive. Millions of dollars in acoustically perfect rooms and expensive and complex equipment are used for this purpose. Another method is to poll groups of people to listen and give opinions of sound properties.

In order to have sound, three things are needed. The first is a source to produce a mechanical movement or sound wave. Second is a medium for the mechanical wave to travel. Third is a detector to receive the sound wave or detect it. The source is anything that produces a vibration. The medium is most often air and the detector is the ear. A sound wave consists of varying changes in air pressure measured in frequencies and stated in hertz (Hz). The human ear is on the average capable of detecting or hearing frequencies of 20 to 20,000 Hz over a very large range of amplitude. The amplitude describes the strength or loudness and is expressed in sound pressure levels. The lowest threshold of loudness is one five billionth of a standard atmospheric pressure change. The largest value is on the order of 1,000,000 microbars. Because of the 1:1,000,000 range of loudness and the logarithmic way the ear perceives sound, the BEL or Decibel is used to express loudness. The Bel or Decibel is not a unit but a relationship between two measurements and is a ratio between two powers expressed as logarithm. The decibel system makes sound power numbers more manageable and also approximates the way human hearing works. This is expressed as a 3 decibel change because the logarithm of 10 is 0.3, therefore three decibels. The decibel is also used to compare voltages in which the other parameters are kept constant, but because the math is different the doubling of voltage represents a 6-decibel change. The important thing is that the decibel or dB is an expression of ratio. The following table will be helpful in expressing dBs.

By definition, the dB is 10 times the common logarithm of the ratio of two powers as expressed on equation (1).

$$N_{dB} = 10\log\left(\frac{P_1}{P_2}\right) \quad \text{.......} \quad (1)$$

where N_{dB} =The number of decibels
P_1 = Power of the generated signal from the source
P_2 = Power of the transmitted/reflected signal from the microphones

It can be seen that a 6dB change in power gives 4 times the loudness and 2 times the voltage or current of a sound signal.

As illustrated in Figure 1, the Clemson – Boston Differential Sound Insulation Tester consists of seven components:

1. The sound signal-processing computer,
2. The sound signal amplifier,
3. The sound source,
4. The sound chamber,
5. The sound detector,
6. The material sample holder,
7. The signal processing software.

The signal-processing computer (1) generates the sound signals. The signals are amplified by the signal amplifier (2). The amplified signals are sent to the sound source (3) to be converted to sound waves. The material to be tested is mounted in on sample holder (6), placed in the sound path. The sound wave is transmitted inside the sound chamber (4) passing through the sample material to the sound detector (5). The sound detector converts the received sound signals to electrical signals and sends back to the signal-processing computer to be analyzed. If no sample is in the path of the sound wave, a background reference is obtained and sample data can be compared to this air reference. If two samples are compared, data from one sample is compared to the other with no changes to the settings of the instrument.

Our sound insulation measurement system is not the perfect sound chamber with perfect acoustical properties, but it gives a comparison of the samples under the same conditions and therefore yields a direct acoustical comparison.

The design of our sound measurement system takes in several other important considerations. The distance between the sound detector and the sound source is one meter. This distance was used because some audio standards use the one-meter distance to measure the sound pressure level of speakers. The holder is mounted on a track allowing the sample to move for variable distances between the source and detector. This was done because the sound pressure varies with the distance from the source and will give more detailed and varied analysis. The sample size is 12 inches by 12 inches. This makes it more convenient to compute and compare samples by the square foot. This also gives a comparison of the fiber arrangement, thickness, surface and the other finished details. Two sound detectors are used; one in front of the sample and one behind the sample. Therefore transmitted and reflected sound can be selected and measured as a comparison. The sound spectrometer can be used to measure the sound insulation difference between two materials. This device tests both transmitted and reflected sound.

The working principle of the Clemson – Boston Differential Sound Insulation Tester is shown in Figure 2. A sound signal is generated by a sound supply program. The sound waves which are in different frequencies travel to the test sample. When the sound waves hit the test sample, some are transmitted, some are reflected, and the rest are absorbed by the test sample. The transmitted waves are sensed by the Microphone 1 and the reflected waves are sensed by the Microphone 2. These sound waves are amplified and sent to a computer. These waves are analyzed by a computer program.

The measurement procedure consists of the following eight steps:

1. The computer is turned on.
2. The sound signal is activated.
3. The amplifier is adjusted to establish a base line.
4. The desired test type (transmitted or reflected) is selected.
5. The test chamber is opened and the test sample is placed in the sample holder.
6. The sound signal is activated and recorded.
7. The result is transformed by Fourier Transformation.
8. The transformed/reflected data is saved.

The sound measurement device measures acoustical insulation by comparing two or more samples. This can be done in two ways: In the first method,

1. A measurement is made without a test sample.
2. The Fourier Transform is applied to the data.
3. A graph between the amplitude and the frequency of the sound is generated by the computer.
4. The data is selected as a base line.
5. The first test sample is placed to a sample holder.
6. The sound signal is activated and recorded.
7. The data is taken as a graph between amplitude and frequency.
8. The data is saved.
9. The other test sample is placed.

10. The sound signal is activated and recorded again..
11. The data is taken as a graph between amplitude and frequency and saved
12. The two results are plotted on the same graph.

In the second method,

1. The first test sample is put to the spectrometer.
2. The sound signal is activated and recorded.
3. The Fourier Transform is applied to the data.
4. The graph between the amplitude and the frequency of the sound is generated by the computer.
5. The data is selected as a base line.
6. The other test sample is placed.
7. The sound signal is activated and recorded again.
8. The result is taken as a graph between amplitude and frequency and saved.

In this paper, the first method was used in order to obtain the sound insulation differences between two or more different fabrics.

Materials Evaluated

Seventeen nonwoven fabric materials with different structural characteristics were obtained for testing. Descriptions of the test materials are shown in Table II.

From the sample population, fabrics with two comparable parameters and at least two different parameters were selected for comparative analysis. To obtain an indication of the effect of fiber shape on acoustical properties, fabrics made from 6 denier polyester round and 6 denier polyester expanded surface area fibers with comparable thicknesses and weights were selected.

To obtain an indication of the effect of fiber mixture on acoustical properties, fabrics made from polyester and poly/cotton fibers with comparable thicknesses and weights were selected.

To obtain an indication of the effect of fabric weight on acoustical properties, nonwoven fabrics with comparable weights at the same thicknesses were selected.

To obtain an indication of the effect of fabric thickness on acoustical properties, nonwoven fabrics with comparable thicknesses at the same densities were selected.

To obtain an indication of the effect of fabric density on acoustical properties, nonwoven fabrics with comparable densities at the same thicknesses were selected. Then nonwoven fabrics with comparable densities at the same weights were selected

To obtain an indication of the effect of film lamination on acoustical properties, nonwoven fabrics laminated to 2 and 0.75mm film with comparable thicknesses and weights were selected.

Test Results and Discussion

The sound spectrometer has the capability of measuring the frequencies between 0 and 25000Hz. Because the frequency range of human hearing is between 20 and 20000Hz, this zone was selected as the test frequency range. The different fiber and fabric parameters were used in order to determine the relationships between the acoustical insulation properties and fiber shape, fiber mixture, fabric weight, fabric thickness, and film lamination.

Two different measurements can be made: One is transmitted sound insulation, measured from microphone 1 and reflected sound insulation, measured from microphone 2. Data from microphone 1 are very appropriate for obtaining the acoustical insulation data; because fever transmitted sound waves yield better insulation. Therefore there is a direct relationship between transmitted data and sound insulation properties. Data from microphone 2 are not very accurate. When generated sound signals touch the test material, some are reflected and some are transmitted. The reflected sound signal continues to bounce in a test chamber and touches the test material several times. Therefore, sound waves detected by microphone 2 are not the only the sound signals that touch the test material, but also the sound signals that reflect from the test material more than once. In addition, the reflected sound signal strongly depends on the surface characteristics of test material.

Figure 3 shows the reflected data for test materials B and C. There is not much difference in sound insulation data of these two samples.

The results are presented as a graph between frequency and amplitude. After the results are plotted, the trend line is added in order to see more clearly the differences between the data observed from different test materials. The trend line was selected as a three-degree polynomial function. The accuracy is not less than 0.85 for the all curves. If the transmitted and reflected sound differences are not more than 1dB, the difference is not significant because of the accuracy of the device and the range of human hearing.

Fiber Shape Effect

The acoustical insulation comparison between the test materials B and C was made to determine the effect of fiber shape. The properties of these test materials are shown in Table III. The expanded surface area fiber used was 4DG.

Test material B is made from round polyester fiber and test material C and is made from 4DG polyester fiber. The thickness and weight of these materials are similar. Material C has better acoustical insulation profile than material B (Figure 4). Therefore it can be said that materials made from 4DG fibers have better insulation properties compared to round fibers. This is expected because 4DG fiber has more surface area and can trap much air than round fibers. If the material has more surface area, there is more possibility for the sound waves to touch the fiber and lose their energy. In addition 4DG fiber can trap more air than round fiber. Air is a good insulator. Therefore, 4DG fibers are better thermal insulator than round fibers, but the sound insulation difference between test material B and test material C is less than one decibel.

Fiber Mixture Effect

The acoustical insulation comparisons between the samples N-O, and P-Q were made to determine the effect of fiber mixture. The properties of these samples are shown in Table IV.

Figure 5, and 6 show that poly/cotton fabric has better sound insulation than polyester fabric. The amplitude difference is about 4dB.

Fabric Weight Effect

The acoustical insulation comparisons between the samples A-L, F-M, and G-M were made to determine the effect of fabric weight. The properties of these samples are shown in Table V.

The compared samples have similar properties. Only the fabric weights are different. Figure 7, 8, and 9 show the results taken from the samples with different weights. Figure 7 and 8 show that there is a frequency at which the amplitude is the same for the two samples. The frequency values lower than that point indicate that lower weight material has better insulation. The frequency values higher than that point indicate that higher weight material has better insulation. From the Figure 9, it is obvious that the higher weight fabric has better insulation. However, the maximum difference is not more than 2dB between two samples.

Fabric Thickness Effect at Similar Density

The acoustical insulation comparisons between the samples D-E, and J-K were made to determine the effect of fabric thickness at similar density. The properties of these samples are shown in Table VI.

It was anticipated that thicker samples at the same density would yield better insulation properties. Figure 10 and 11 show this result very clearly. The amplitude difference is almost 6dB between test materials D and E at the frequencies greater than 12000Hz. For material with higher thickness at similar densities, there is greater chance for the sound wave to touch the fiber and lose its energy. In addition, trapped air is good insulator. When the material thickness increases, there will be more trapped air, therefore better insulation.

Fabric Thickness Effect at Similar Weight

The acoustical insulation comparisons between the samples I-K, and L-K was made to determine the effect of fabric thickness at similar weight. The properties of these samples are shown in Table VII.

Figures 12 and 13 show that sound insulation change marginally with increased thickness. Sample weights of the samples are similar in this case. When the thickness of sample increases at the same weight, density decreases and the amount of fiber in the test material does not change much. Therefore, sound waves that touch the test material will not lose more energy than before. That is why there is not much difference between these samples that are shown in Figure 12 and 13.

Film Lamination Effect

The acoustical insulation comparison between the test samples L-N was made to determine the effect of film lamination. The properties of these samples are shown in Table VIII.

Hi-loft nonwoven fabrics can be laminated to films after they are produced. The lamination can be applied to increase the acoustical insulation performance of the fabric. Figure 14 shows this effect very clearly. The sample that is film laminated is much better insulation profile than the sample that is not film laminated. The other properties of the fabrics are the same. The maximum amplitude difference is about 10dB at a frequency of 15000Hz. This means that the film-laminated sample insulates the sound that has 15000Hz two times more than the sample that is not laminated.

Summary and Conclusions

The effects of fiber and fabric properties on acoustical insulation are discussed. When the thickness or weight of the test materials increases at the same density, the acoustical insulation improves. When the sample is film laminated, the acoustical insulation improves dramatically. Fabrics made from expanded surface area fiber have marginally better insulation than round fiber. Finally, poly/cotton nonwoven fabric has better insulation properties than polyester nonwoven fabric.

Table 1.

N_{dB}	Approximate Power Ratio	Approximate Voltage or Current Ratio
3	2.0	1.41
4	2.5	1.59
6	4.0	2.0
7	5.0	2.24
9	8.0	2.82
10	10	3.36
20	100	10.0
23	200	14.1
30	1000	31.6

Table 2. Test samples used for acoustical comparison measurements.

Sample	Material Description	Thickness (in)	Weight (g/ft²)
A	Round PET	0.95	105.1
B	Round PET	0.39	42.3
C	Expanded Surface PET	0.34	42.1
D	Round PET/Cotton	0.41	59.5
E	Round PET/Cotton	0.79	117.2
F	0.5" Loft	0.48	37.46
G	0.5" Loft	0.56	52.38
H	2mm Film Laminated	0.5	51.8
I	0.6" Loft	0.54	48.8
J	0.5" Loft	0.37	13.44
K	Hi-Loft	1.62	51.8
L	1.125" Loft	0.88	41.61
M	0.75" Loft	0.47	19.55
N	Fiber(75%):PES, Bin (25%):Vinyl Acetate	0.18	32.56
O	Fiber(75%):35%PES/65%Cotton, Bin (25%):Vinyl Acetate	0.15	34
P	70% Cotton / 30% PET	1.05	76.12
Q	100% PET	1.13	67.42

Table 3. Test samples used for acoustical comparison measurements.

Sample	Material Description	Thickness (in)	Weight (g/ft²)
B	Round PET	0.39	42.3
C	Expanded Surface PET	0.34	42.1

Table 4. Test samples used for acoustical comparison measurements.

Sample	Material Description	Thickness (in)	Weight (g/ft²)
N	Fiber(75%):PET, Bin (25%):Vinyl Acetate	0.18	32.56
O	Fiber(75%):35%PET/65%Cotton, Bin (25%):Vinyl Acetate	0.15	34
P	70% Cotton / 30% PET	1.05	76.12
Q	100% PET	1.13	67.42

Table 5. Test samples used for acoustical comparison measurements.

Sample	Material Description	Thickness (in)	Weight (g/ft²)
A	Hi-Loft	0.95	105.1
L	1.125" Loft	0.88	41.61
F	0.5" Loft	0.48	37.46
G	0.5" Loft 2oz	0.56	52.38
M	0.75" Loft	0.47	19.55

Table 6. Test samples used for acoustical comparison measurements.

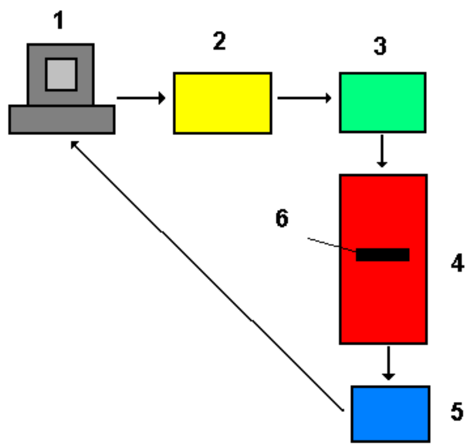
Sample	Material Description	Thickness (in)	Weight (g/ft²)
D	Round PES/Cotton	0.41	59.5
E	Round PES/Cotton	0.79	117.2
J	0.5" Loft	0.37	13.44
K	Hi-Loft	1.62	51.8

Table 7. Test samples used for acoustical comparison measurements.

Sample	Material Description	Thickness (in)	Weight (g/ft²)
I	0.6" Loft	0.54	48.8
K	Hi-Loft	1.62	51.8
L	1.125" Loft	0.88	41.61

Table 8. Test samples used for acoustical comparison measurements.

Sample	Material Description	Thickness (in)	Weight (g/ft²)
H	2mm Film Laminated	0.5	51.8
I	0.6" Loft	0.54	48.8



1. Computer
2. Amplifier
3. Sound Source
4. Sound Chamber
5. Sound Detector
6. Sample Holder

Figure 1. Components of the Clemson – Boston Differential Sound Insulation Tester.

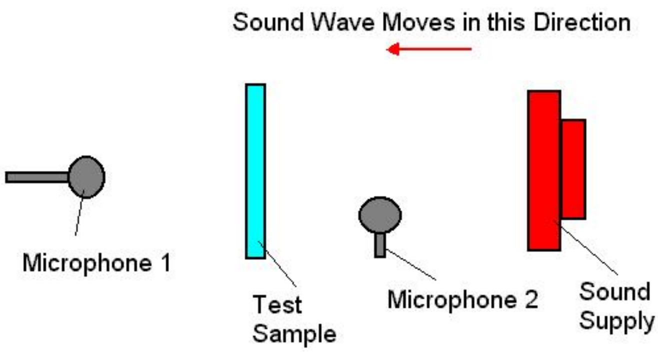


Figure 2. The Working Principle of the Clemson – Boston Differential Sound Insulation Tester.

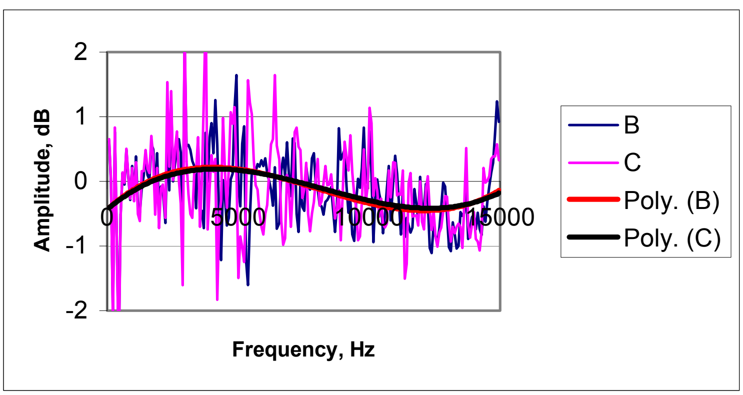


Figure 3. Reflected Sound Results for Test Materials B and C.

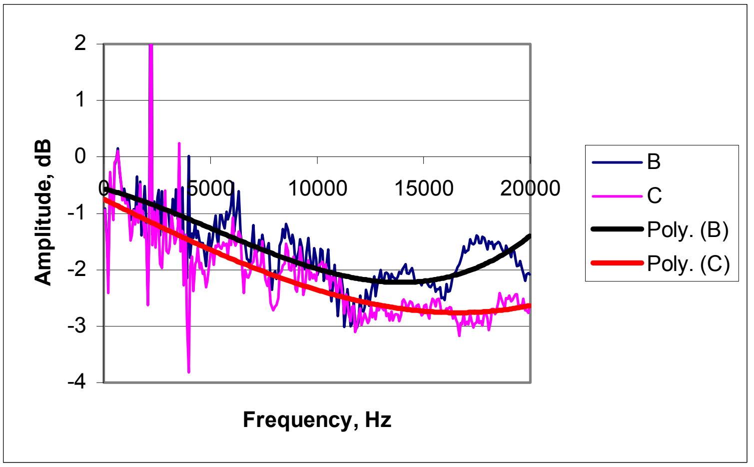


Figure 4. Transmitted Sound Results for Test Materials B and C.

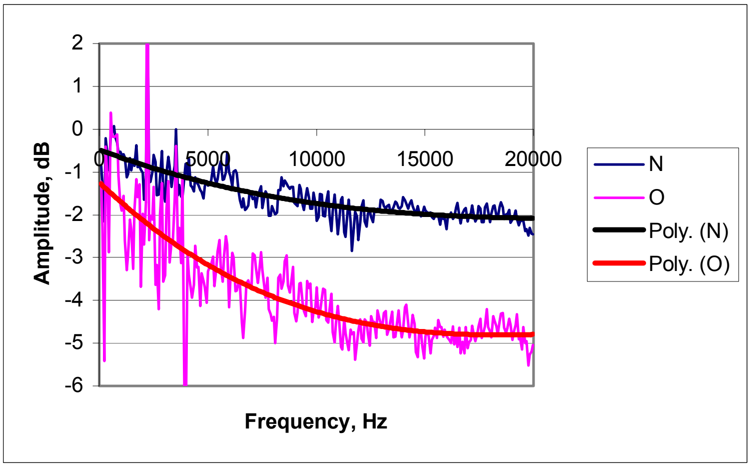


Figure 5. Transmitted Sound Results for Test Materials N and O.

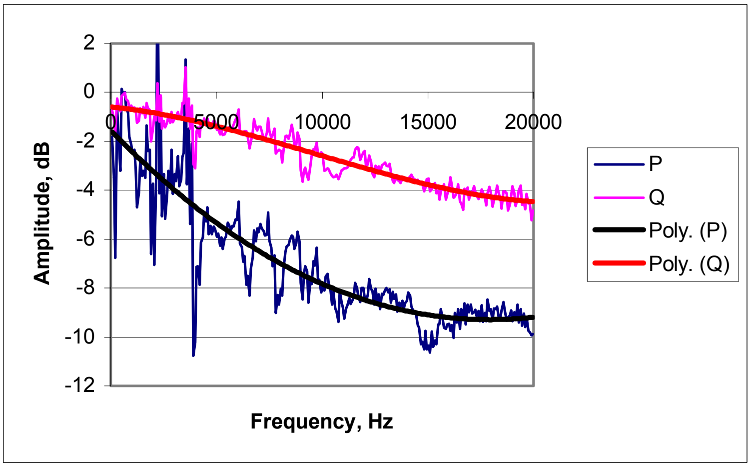


Figure 6. Transmitted Sound Results for Test Materials P and Q.

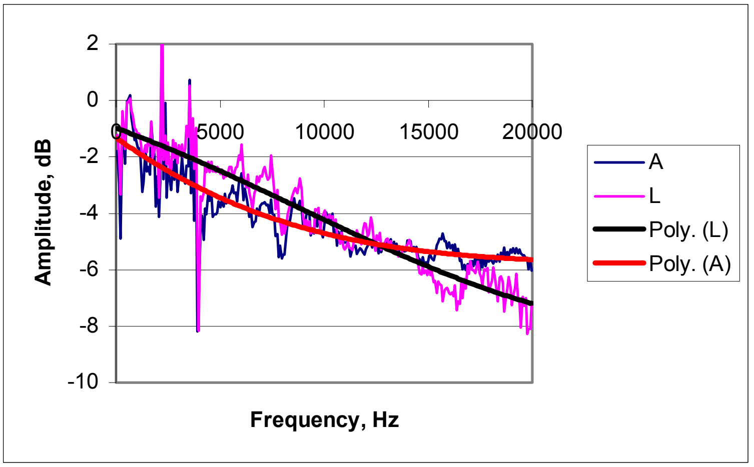


Figure 7. Transmitted Sound Results for Test Materials A and L.

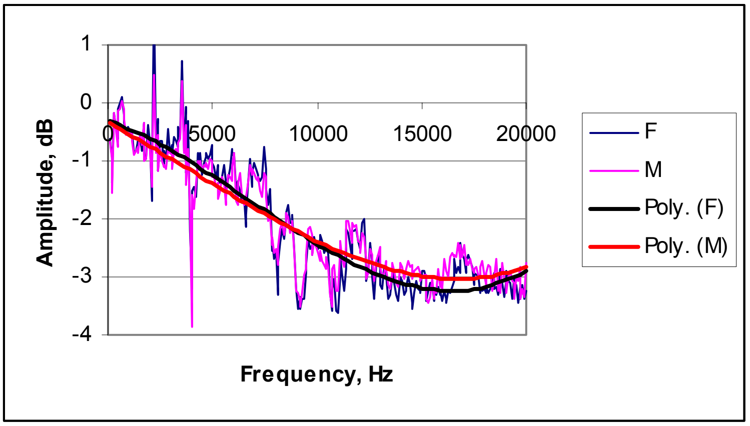


Figure 8. Transmitted Sound Results for Test Materials F and M.

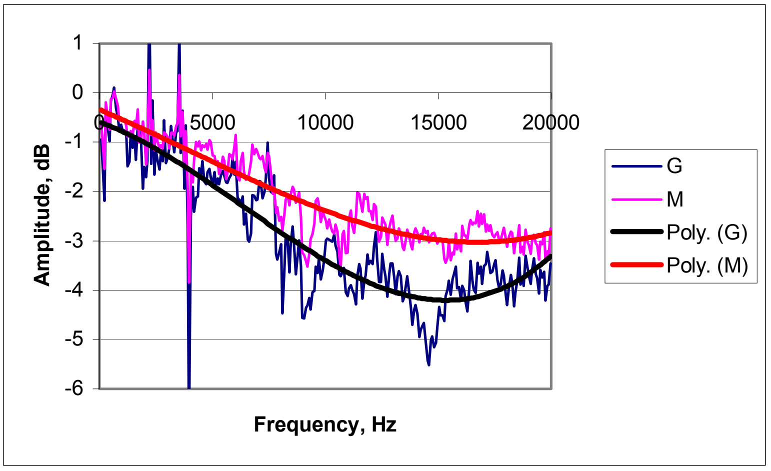


Figure 9. Transmitted Sound Results for Test Materials G and M.

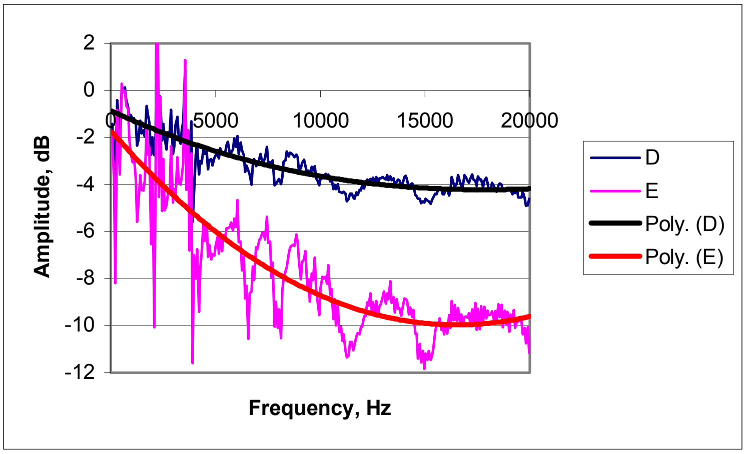


Figure 10. Transmitted Sound Results for Test Materials D and E.

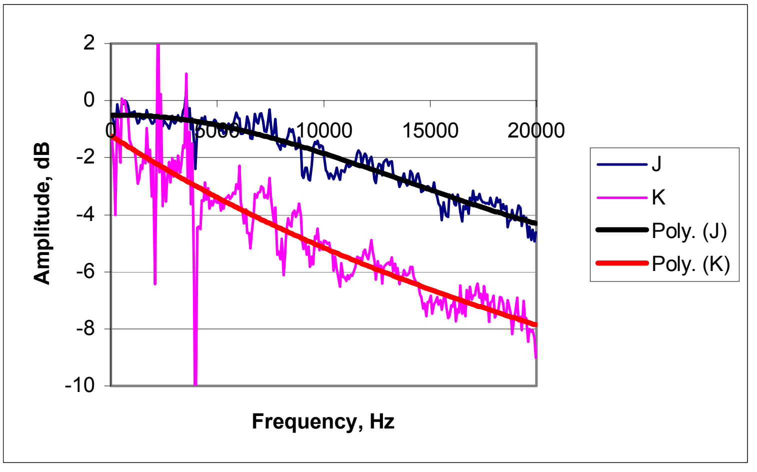


Figure 11. Transmitted Sound Results for Test Materials J and K.

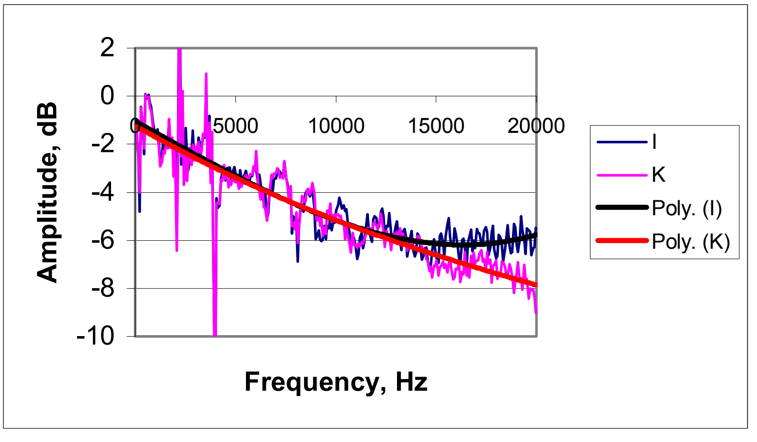


Figure 12. Transmitted Sound Results for Test Materials I and K.

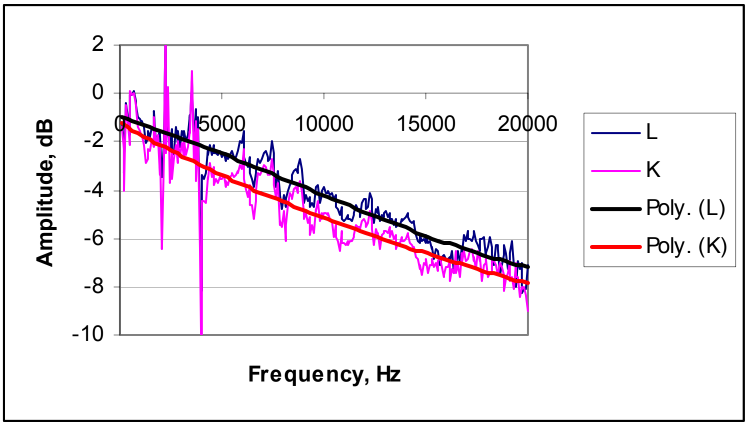


Figure 13. Transmitted Sound Results for Test Materials L and K.

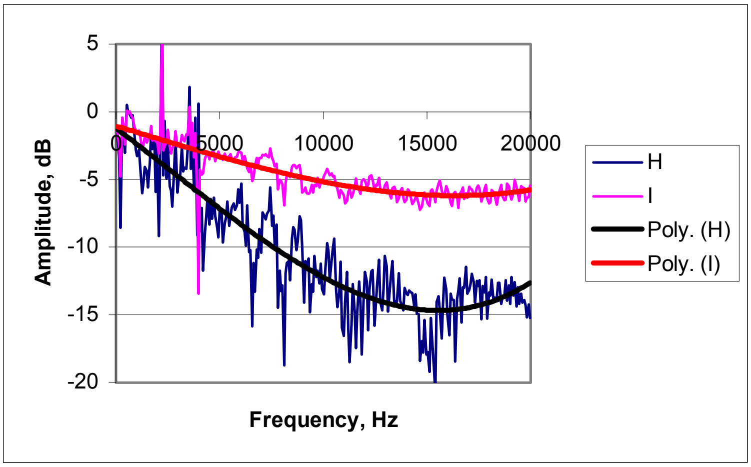


Figure 14. Transmitted Sound Results for Test Materials H and I.