Modelling of Sound Spectral Properties in Noise Suppression Engineering Materials

Preliminary Communication

Marija Kovačević
J.J. Strossmayer University of Osijek
Faculty of Electrical Engineering
Kneza Trpimira 2b, 31000 Osijek, Croatia
marija.kovacevic@etfos.hr

Dario Pović
J.J. Strossmayer University of Osijek
Faculty of Electrical Engineering
Department of Electromechanical Engineering
Kneza Trpimira 2b, 31000 Osijek, Croatia
dario.povic@etfos.hr

Tomislav Keser
J.J. Strossmayer University of Osijek
Faculty of Electrical Engineering
Department of Electromechanical Engineering
Kneza Trpimira 2b, 31000 Osijek, Croatia
tomislav.keser@etfos.hr

Abstract *–A modern way of life has also brought the problem of noise and its impact on both human health and the quality of life in general. There is an act in the Republic of Croatia that stipulates the permitted noise emissions for specific areas, but it also sets out that every bigger city should try to avoid hazardous noise. When it comes to traffic, there are several noise sources and methods to decrease noise. A specific mixture of paving materials can result in a different impact on the noise level. Measurements have shown that several materials act differently depending on the noise bandwidth, so a specific mixture of materials may bring to a noticeable decrease in traffic noise. The main goal of this paper is to develop a more efficient and reliable method to identify the sound characteristics of building materials with respect to the reduction of environmental noise. The method is based on spectral analysis of the absorption of a sound image of the analyzed material in order to identify and build their graph and analytical models*

Keywords *– graph and analytical model, noise impact, noise sources, permitted noise emission, sound spectral properties*

1. INTRODUCTION

Due to a modern way of life, there is a noise problem. Noise is every unwanted sound that interrupts the usual rhythm of life. Therefore, it has become one of the major problems of the modern world. There are many different noise sources, but when it comes to classification, we distinguish natural and artificial or human-made noise. Since noise is a sound, it is measured in a unit of noise level – decibel [dB]. Because noise is a major problem, it must somehow be reduced. The simplest way is to reduce noise at its source. Motor vehicles are one of the main sources of noise, which we will discuss below, but because of their inevitable application and appliance it is impossible to simply remove them, so it is necessary to find another solution. If you cannot remove the noise source, it is necessary to prevent its spread. Since the largest amount of noise is generated as the interaction between vehicles and road surfaces, it is necessary to act exactly at that place. Because of this knowledge, the focus of this paper will be on the process of designing sound spectral properties in noise suppression engineering materials that are used in the process of road construction whose properties can contribute to a noticeable decrease in traffic noise. Furthermore, the connection between noise and the construction material made for noise suppression will be described. As a major part of this paper we will present a new method of evaluation of designed road cover specimens. The method is based on spectral analysis of the sound absorption of individual specimen. The measurement results are presented in form of graphs showing the amount of the absorbed sound pressure in dependence on the frequency of the excitation signal. The excitation signal is a sine wave with a specified frequency. The resulting graphical model shows the intensity of the sound at different frequencies. Depending on the obtained results, the best mixture of materials that absorbs noise best will be presented.

After the opening statements in Section 2 we show the impact of noise on human health and state legal requirements intended to limit the impact of noise. In Section 2, we explain sources of noise in road traffic and list some of the noise reduction approaches. Section 4 provides a theoretical assumption required in the process of material modelling. We also present the method of evaluation of the designed materials using the improved existing methods. In the last section, we present the results of measurements that we have conducted in laboratory conditions using the method described in previous sections. We start with showing the impact of noise on humans to indicate a great need to reduce this problem.

2. NOISE AND HUMAN HEALTH

Noise has an undeniable impact on human health and the quality of life. Exposure to noise is omnipresent and there is no way to avoid noise. Just walking through the street while traffic surrounds us has an impact on human health and long-term noise exposure may cause health difficulties.

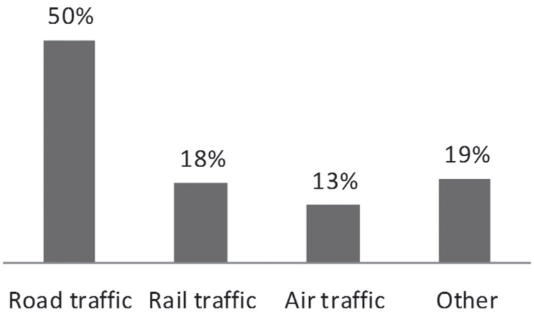

Fig. 1. Global noise contribution of particular traffic noise sources.

A noise level of 60 dB has a psychological impact on humans, while a noise level of 70 dB can damage our hearing, [1]. Traffic noise presents 80% of all noise in urban areas, so traffic is one of the main noise sources. On the basis of noise emission, road traffic is a major pollution source followed by rail traffic and air traffic. Figure 1 shows contribution of particular noise sources to global noise sources, [2]. According to Table 1, the loudness of traffic noise can be divided into five groups depending on the type of a motor vehicle. Cars produce noise of 70 dB, which is more than the aforementioned 60 dB, and long-term noise exposure definitely has consequences on human health, [3].

Table 1. Average noise levels emitted by different types of motor vehicles.

Intensity	Type of vehicle
70 dB	cars
85 dB	lorry
90 dB	motorbike, tram, train
100 dB	small aeroplane
120 dB	big aeroplane

In addition to traffic, a very dangerous type of noise is the one caused by construction activities, which are omnipresent in big cities. In what follows we deal with the acts of the Republic of Croatia concerning the maximum permissible noise levels in populated areas.

2.1. LEGAL NORMS RELATED TO NOISE IN POPULATED AREAS

Cities are the main sources of very dangerous noise. In terms of noise sources in cities, there are a lot of sources such as traffic, civil engineering, human activities such as concerts, public events, etc. When it comes to noise protection in cities, local government and lawmakers pass acts and standards that describe which noise levels should be respected in cities. There is one active act in the Republic of Croatia that prescribes the maximum allowed noise level for each city zone, i.e., the Noise Protection Act, [4]. There is a difference between day/night noise and it is designated by *Lden*, *Lday*, *Levening*, *Lnight*. *Lden* is a noise indicator for the entire noise disturbance; *Lday* is a noise indicator for the day period, *Levening* is a noise indicator for the evening period and *Lnight* is a noise indicator for the night period. Noise levels refer mainly to noise produced by humans. The maximum permitted noise emission level is divided into five zones based on the criterion of the purpose of a certain zone. The maximum noise level in zones designated for medical and relaxing purposes is 50 dB during the day and 40 dB during the night. Maximum noise levels in living areas are 55 dB and 40 dB during the day and during the night, respectively. Noise levels in predominantly residential areas are 55 dB during the day and 45 dB during the night. Areas whose purpose is mixed should not be louder than 65 dB during the day and 50 dB during the night. Economy areas have a boundary noise level of 80 dB. According to noise levels in specific areas, cities with more than 250,000 inhabitants are obliged to make strategic noise maps and action plans. The City of Osijek is one of biggest cities in the Republic of Croatia and it is considered to be one of the calmest cities. Despite this, there are streets which exceed the allowed noise levels. Consequently, the City of Osijek has developed noise maps and in some areas noise reaches 60 dB during the night. Figure 2 shows part of the noise map made for the City of Osijek. All areas colored blue indicate the maximum noise level for the area shown on the map, while all yellow areas indicate the lowest noise level. Since the displayed area on the map is mostly residential by its purpose of usage, it is necessary to take certain measures to reduce noise sources.

Because of this problem, which is largely emphasized in urban areas, it is necessary to resort to new methods of preventing noise. The design of a new pavement structure is one of the possible solutions to the problem of noise in the city that will be described in the following sections.

Fig. 2. Noise map of the City of Osijek, [5].

In the text that follows we deal with methods of reducing noise sources using the available measures.

3. MAIN SOURCES OF TRAFFIC NOISE

There are three main steps in the process of reducing noise in populated areas. First, we need to identify the sources of noise and then we can move on to the design and implementation of noise reduction measures.

3.1. NOISE SOURCES

As already mentioned, the main source of noise in cities is traffic. Among all kinds of transportation means motor vehicles certainly produce most of noise pollution. There are several sources of noise that are directly or indirectly related to motor vehicles. Noise sources can therefore be divided into three subtypes, [6]:

1. noise generated as the interaction between a motor vehicle and air,
2. noise generated by motor vehicle parts,
3. noise generated as the interaction between motor vehicle tires and the road surface.

The noise generated by the interaction of a motor vehicle and air occurs as a result of vehicle movement through space at a certain speed. Regardless of the design of the vehicle itself (aerodynamic properties), the amount of noise produced by the movement of the vehicle is minimal. Another type of noise is noise caused when the motor vehicle is running. Depending on load and engine speed, engine noise varies. Besides the engine, a large amount of noise is generated by the system for delivering air to the engine. On the other hand, there is a system for the expulsion of exhaust gases formed as a product of combustion of gasoline in the engine. Besides the noise caused by engine operation, the engine cooling system greatly contributes to the generation of noise, [6]. The amount of noise is expressed in decibels. The dependence of the emitted noise and engine rpm is almost linear. Already at 2000 rpm the amount of emitted noise reaches a 60 decibels limit. We are aware that most drivers do not drive conscientiously and therefore the amount of noise certainly exceeds this limit. As a separate category, which greatly contributes to the generation of noise, is the noise created by the interaction of the tire and the ground. The quantity of noise depends on the structure of the substrate, the type of tire and the vehicle speed. If the vehicle speed is increased by one quarter, tire noise will increase twice. The noise is more pronounced on tires with transverse grooves than on tires with oblique or longitudinal grooves. Road conditions also affect the level of noise, so roughened pavement creates more noise. Weather conditions affect the amount of emitted noise as well. Wet pavement greatly increases the amount of noise. Noise produced when a motor vehicle uses wet pavement is particularly pronounced at lower speeds. Vehicle load can also be singled out as one of the factors in the generation of noise, [7]. Figure 3 depicts the total emitted noise level characteristics of a vehicle as the acoustic sum of the noise caused by the interaction between tires and pavement and the noise created when vehicle parts are in operating mode.

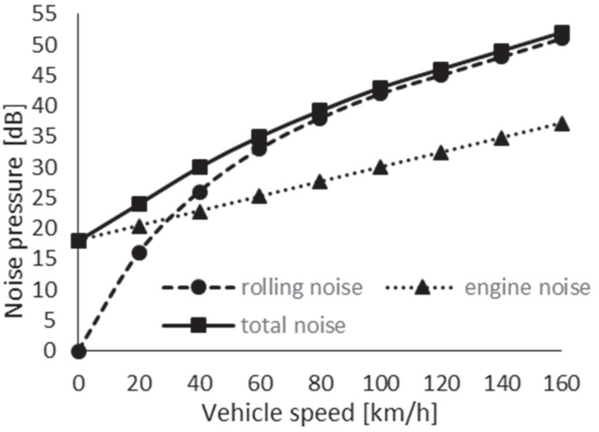

Fig. 3. Pressure level characteristics of vehicle noise sources related to its speed.

We can see how the tire noise at 30 km/h becomes dominant, so we can conclude that the main cause of the overall noise emitted in urban areas occurs as a result of interactions between the tires and the ground. In the following text, we present methods of noise reduction, both in the vehicle and on roads where most of the noise is generated, [3].

3. 2. NOISE SUPRESSION METHODS

Methods used to reduce the amount of noise are carried out in three places:

1. at the source of the noise (vehicle parts),
2. in the process of noise transmission,
3. on the receiving side.

In what follows we will focus on noise reduction at the source of the noise origin since it is the most common type of noise. We have concluded that the noise produced by the motor vehicle parts while vehicle is in operating mode is the main problem at speeds below 30 km/h. Accordingly, we can do the following steps to reduce the amount of the emitted noise at the source.

Engine - reduce vibration, acceleration control, cover the area around the engine with soundproofing materials.

Cooling - reduce the angular speed of the fan, use a diffuser, a larger radiator, etc.

Air intake - change the intake system location, use a diffuser, etc.

Exhaust - use silencers, vibration reduction, etc.

Tire - change the shape, material, load and speed of tire, etc.

Among other measures, the noise source can be controlled even in the following ways:

- by limiting the maximum allowable speed of motor vehicles for the particular location in a populated area,
- by maintaining the roadway and the motor vehicle,
- by regulating traffic density (redirect vehicles to a bypass road),
- by applying legal norms (punishing drivers for violating traffic rules), and
- by selecting the type of road surfaces (concrete is noisier than asphalt).

Once we have determined the main sources of noise, and after having explained some of the ways how to reduce the creation and emission of noise, special attention will be given to the usage of new materials in the construction of the roadway in order to reduce the noise caused by the interaction between tires and road surfaces.

4. MODELLING OF ENGINEERING MATERIALS

As noted above, at speeds of over 30 km/h the noise produced from the interaction between tires and road surfaces is becoming dominant, hence it is necessary to pay special attention to this problem. This noise can be separated into noise caused by the type of road surface and noise caused by the properties of the tire. In what follows attention will be paid to the noise created due to the properties of road surfaces.

4.1. SOUND SPECTRAL PROPERTIES

The main goal is to find a way to reduce noise using new construction materials capable of decreasing the noise level to an acceptable value. Many analyses and studies have shown that, when it comes to a specific mixture of asphalt and concrete, the viscoelastic property has a big influence on tire/pavement noise [8]. Different surfaces act differently and consequently they have a different impact on the noise level. Road surface can be divided into two main groups, i.e., asphalt and concrete surface. As a substrate, both types of road surfaces have a loaded stone where asphalt or concrete slabs are then placed. Concrete is structurally rigid, while asphalt contains elastic properties. The basic characteristic of the driving surface that must be satisfied is called the acoustical absorbance (it is a measure of the percentage of the absorbed sound waves impacting the surface). A higher value of the acoustic absorption means that the given surface is more suitable for the application. In other words, vibrations caused by the interaction between tires and road surfaces due to a high acoustical absorption coefficient are transferred to the substrate (instead of surrounding air). Of course, part of vibrations is transmitted by air but the noise level is significantly reduced. The main subtype of asphalt designed precisely to reduce the noise level is called porous asphalt. Single-layer porous asphalt reduces 3-4 dB of noise. Also, if we put another layer of porous asphalt, the reduction will be 4-6 dB. One the other hand, porous asphalt has disadvantages such as clogging. Clogging reduces drainage abilities and noise reduction as well. A more complex version of asphalt is called a poroelastic road surface and it is made as a mixture of a large percentage of rubber particles mixed with hard aggregate and all of that is at the end bounded with polyurethane. This type of asphalt can reduce noise up to 10 dB, [9]. Nevertheless, insufficient performance and lower friction properties represent major problems of poroelastic asphalt and that is why it has not been applied yet. Another type of asphalt is known as “an asphalt rubber friction course”. It is a gap-graded or open-graded asphalt mix which contains 15 to 20 percent of crumb rubber, and it is capable of reducing noise by 2 dB [10, 11]. The last subtype of asphalt road covers is called stone mastic asphalt (SMA), a gap-graded friction course with voids filled with a considerable amount of asphalt, stabilizer and finer aggregate. SMA reduces the noise level by 3 dB, but because of its disadvantages it is not as popular as other mixtures. In a group of concrete substrates, we can highlight pervious concrete that is considered as “quiet” and it consists of 11-35% void content. It decreases noise emission and provides good drainage capacity. So far, methods have not measured the spectral response on a monoharmonic signal (under the spectral response we consider conduction and reflection of sound through the test sample). Our method is based on laboratory measurements of the spectral response of test samples (concrete slabs). A sinusoidal wave with a specified frequency is used as an excitation signal while a spectral model (a graphical model) is obtained from data collected by means of s professional sound meter. Therefore, our method will be just based on the upgrading of shortcomings of the aforementioned methods.

4.2. TEST SETUP

In order to ascertain the effectiveness of noise reduction it is necessary to conduct measurements on materials road surfaces are built of. These measurements can be carried out in the laboratory or directly at the place where these materials are applied. The advantage of the measurement method at the place where noise reduction materials are applied is that the derived values are created in real conditions (a different number of vehicles, different types of vehicles, sudden acceleration and stopping of the vehicle, the interaction of tires and road surfaces, etc.).

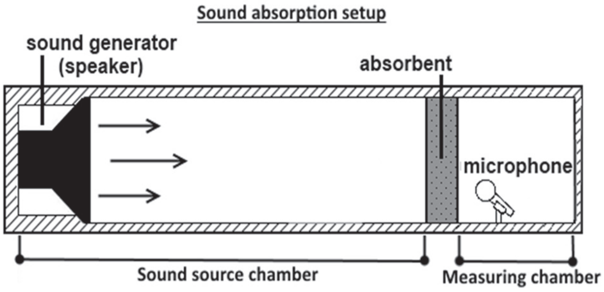

Fig. 4. A schematic diagram of an impedance tube used for measurement of the acoustic absorption coefficient of a given specimen absorbent.

Data is collected by setting the instrument along the road or directly on the vehicle. The main disadvantage of this method is that the resulting information is accurate only for the measuring conditions that prevailed at the time of measurement. On the other hand, measurement in the laboratory is strictly controlled and it allows a more precise determination of the properties of materials. In Figure 4, we can see a schematic diagram of an impedance tube used for measurement of the acoustic absorption coefficient of a given absorbent. An absorbent represents the road surface that must be able to absorb most of the noise produced as the interaction between the tire and the road. On the left-hand side of the impedance tube is a source of noise (in this case the speaker). Part of the impedance tube where the speaker is placed is also called a sound source chamber. The speaker must be able to reproduce noise with specific frequency values. The noise must be in the following frequency interval

f Ξ [20Hz, 20kHz]. The specified frequency range is also the area that we hear with our ear. In this case, a microphone is placed in the chamber placed after the specimen. Part of the impedance tube where the microphone is placed is also called a measuring chamber. The role of the microphone is to measure the amount of sound passing through the specimen. In addition to noise absorption, another method is to measure the amount of noise reflected from the specimen. In the space between the source of noise and the specimen there are two microphones. One microphone measures noise produced by the source while the other one measures the reflection of sound from the surface. Figure 5 shows a schematic diagram of an impedance tube used for measuring the acoustic reflection coefficient of the given specimen absorbent.

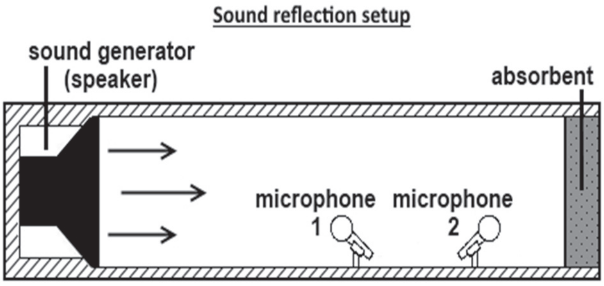

Fig. 5. A schematic diagram of an impedance tube used for measuring the acoustic reflection coefficient of the given specimen absorbent.

The main disadvantage of this method is the potential impact of the material the impedance tube is built from on the measurement results. Additionally, the acoustic tunnel must be sufficiently long to ensure a stable plane-wave sound field. Best measuring results are given if we use both methods. Figure 6 shows the impedance tube used for measuring the acoustic absorption coefficient of the given absorbent (specimen) used for our measurements. The impedance tube used in our measurements is made according to the schematic diagram given in Figure 4. In the text that follows we present measurements conducted on several pavement specimens.

4.3. TEST RESULTS AND SOUND MODELS

After having determined the methods by which we will conduct measurements, we will present the results of our work. Measurement was carried out on the model shown in Figure 6. As a source of noise, we have used the speaker. The sound level was measured by using a professional measuring instrument (*Bruel & Kjaer* type *2260*).

The results will be presented in form of tables and graphs. Since the area of human hearing ranges from 20Hz to 20kHz, the above described measurement is carried out just in the given interval. We paid special attention to the frequency of 1000Hz at which the human ear is most sensitive. In areas below 20Hz and above 10kHz, sensitivity of the ear decreases significantly. In Table 2, we can see specific measurements carried out in laboratory conditions described in the previous text. The first column (F0) in Table 2 represents sound frequencies generated by computer and reproduced on the speaker during the test. Column L0 is the reference noise measurement without a specimen. LM1 is a specimen with the worst noise absorption properties, while specimen LM2 is a specimen with the best noise absorption properties.

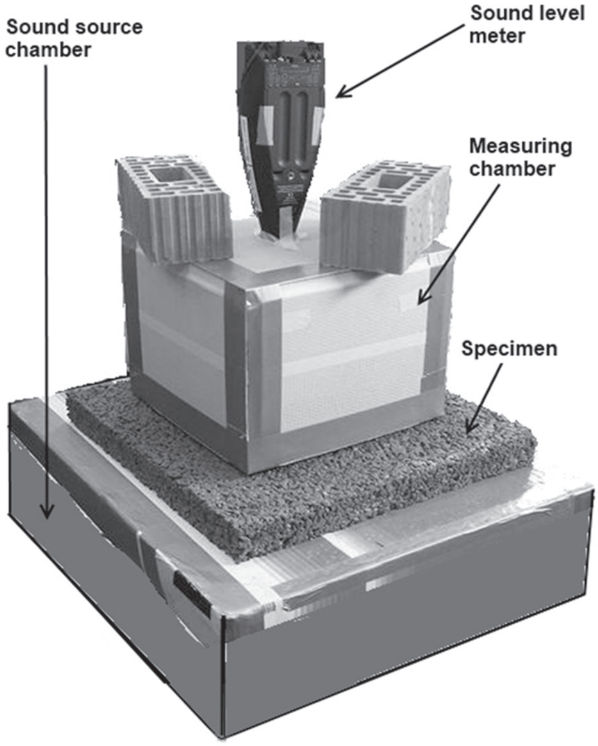

Fig. 6. Impedance tube used for measuring the acoustic absorption coefficient.

In addition to these three samples, measurements were also performed on another three samples whose results ranged between LM1 and LM2. These samples are called LM3, LM4 and LM5. Each sample varies according to the material it was made from. Other parameters are identical (noise source, dimensions of the specimen, duration of data collection, environmental impact on the measurement, measuring device).

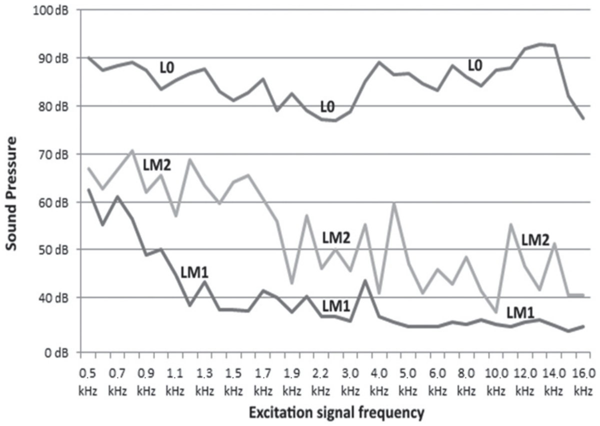

Fig. 7. Spectral model of tested specimens (L0, LM1 and LM2).

Figure 7 shows the spectral model of tested specimens obtained from the data shown in Table 2. The ideal curve should be as close to the reference curve L0 (noise measurement without specimen) as possible.

Tab. 2. Measuring parameters of tested specimens (reference noise value, specimen with the worst and best noise absorption properties)

F0	L0	LM1	LM2
0.5 kHz	90.0 dB	62.5 dB	66.8 dB
0.6 kHz	87.5 dB	55.3 dB	62.8 dB
0.7 kHz	88.3 dB	61.1 dB	66.7 dB
0.8 kHz	89.0 dB	56.4 dB	70.7 dB
0.9 kHz	87.4 dB	49.0 dB	61.9 dB
1.0 kHz	83.5 dB	50.1 dB	65.4 dB
1.1 kHz	85.3 dB	44.7 dB	57.0 dB
1.2 kHz	86.7 dB	38.3 dB	68.8 dB
1.3 kHz	87.7 dB	43.2 dB	63.3 dB
1.4 kHz	83.0 dB	37.5 dB	59.7 dB
1.5 kHz	81.1 dB	37.5 dB	64.0 dB
1.6 kHz	82.7 dB	37.3 dB	65.5 dB
1.7 kHz	85.5 dB	41.5 dB	60.7 dB
1.8 kHz	79.1 dB	40.0 dB	55.9 dB
1.9 kHz	82.6 dB	37.0 dB	43.0 dB
2.0 kHz	79.1 dB	40.2 dB	57.0 dB
2.2 kHz	77.1 dB	36.0 dB	46.2 dB
2.6 kHz	76.9 dB	36.0 dB	50.0 dB
3.0 kHz	78.8 dB	35.2 dB	45.6 dB
3.5 kHz	85.2 dB	43.5 dB	55.2 dB
4.0 kHz	89.1 dB	36.0 dB	40.9 dB
4.5 kHz	86.5 dB	35.0 dB	59.6 dB
5.0 kHz	86.7 dB	34.0 dB	47.1 dB
5.5 kHz	84.6 dB	34.0 dB	41.0 dB
6.0 kHz	83.2 dB	34.0 dB	45.9 dB
7.0 kHz	88.3 dB	35.0 dB	42.9 dB
8.0 kHz	86.0 dB	34.5 dB	48.5 dB
9.0 kHz	84.1 dB	35.3 dB	41.5 dB
10.0 kHz	87.5 dB	34.5 dB	37.1 dB
11.0 kHz	87.9 dB	34.0 dB	55.3 dB
12.0 kHz	92.0 dB	35.0 dB	46.5 dB
13.0 kHz	92.9 dB	35.3 dB	41.7 dB
14.0 kHz	92.6 dB	34.3 dB	51.3 dB
15.0 kHz	82.1 dB	33.0 dB	40.4 dB
16.0 kHz	77.5 dB	34.0 dB	40.5 dB

We can see that the specimen LM2 has a better acoustic absorption coefficient at all frequencies than the worst specimen LM1 (curves do not intersect). We can also see that the minimum deviation between the reference curve L0 and the specimen LM2 curve is at a frequency of 1 kHz. That is why this type of cover could be of great benefit. Figure 8 shows characteristics of the remaining three samples.

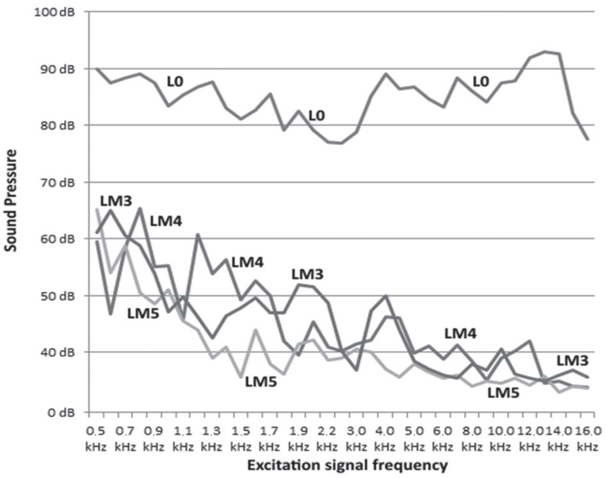

Fig. 8. Spectral model of tested specimens (L0, LM3, LM4 and LM5).

The properties of these three samples are constantly intertwined so we can conclude that each kind of cover is suitable for usage at a particular frequency. At some frequencies, some of these features show better performance than the sample LM2. In Figure 9, we can see the features of all five samples. At the indicated positions (points A, B, C and D) the sample LM3 shows better performance than the best sample LM2. In order to get a perfect solution it is necessary to apply a structural property adjustment of both materials in order to obtain the ideal material for making roadway surfaces.

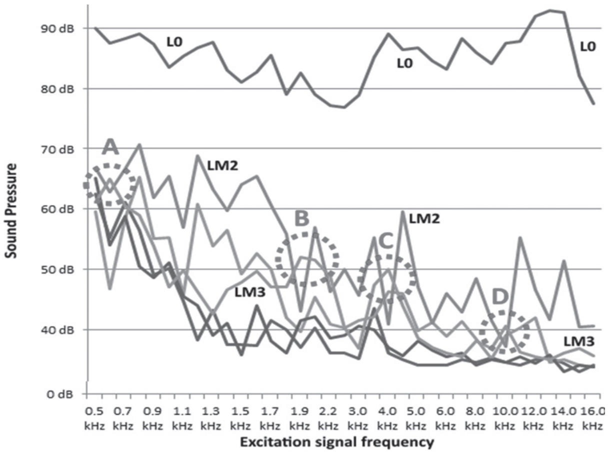

Fig. 9. Spectral model of tested specimens (L0, LM1, LM2, LM3, LM4 and LM5).

From the resulting spectral model we can conclude that the given driving surface greatly reduces noise reflection in the surrounding area. The measurements listed above show features only for a few tested samples. More extensive measurements on multiple samples are necessary to confirm the quality and accuracy of the used methods. Finally, the application of the tested samples will give the actual values that will be the reference for determining the accuracy of the method. Based on the results, we can conclude that the method is very successful and this confirms all theoretical assumptions listed above.

5. CONCLUSION

Although there are regulations in every country that provide some protection from noise, there are still a lot of areas where the only way to solve the problem with noise is to reduce it. While researching noise and how different materials act when it comes to noise, we may come to the conclusion that noise can be reduced with a specific mixture of materials. The main reason why noise should be reduced is the fact that noise has a big impact on human health and the quality of life in general. So far, methods have not measured the spectral response of specimen tested on a monoharmonic signal (under the spectral response we consider conduction and reflection of sound through the test sample). Using the method based on spectral analysis of the absorption of a sound image of the analyzed material we can identify and build graphical models. The resulting graphical model shows the intensity of the sound at different frequencies. The results of the measurements are presented in form of graphs showing the amount of the absorbed sound pressure and dependence on the frequency of the excitation signal. A sinusoidal wave with a specified frequency is used as the excitation signal, while the spectral model (the graphical model) is obtained from data collected by means of a professional sound meter. Therefore, our method will be based just on upgrading the shortcomings of the previously stated methods.

Future work may outline possible upgrades in the process of data collection. Since in the process of data collection we had to read the data, enter the measured data into the database and generate the excitation signal for each measurement manually, development of a standalone application that will do all of this work automatically, would be of great help. In addition, it is possible to create a simulation environment, which would include the database of the measured data together with the properties of each specimen. If we have a sufficiently large database, it would be possible to design new materials without the need to physically prepare the test specimen. That would save both time and money.

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