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Technical Note

Research of Chosen Acoustics Descriptors of Developed Materials from Old Automobile Recycled Materials †

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Abstract: Legislative regulations and standards have been approved for noise control, aimed at controlling noise minimization. This problem is also under the public interest, because noise is increasing in many counties. EU directive 70/157/eec determines and controls limits of environmental noise and is aimed at creating less noisy and more pleasant outdoor and indoor environments for European residents within "sustainable development in Europe". This study focused on the utilization of new, so-called acoustic more convenient materials, based on and produced from old materials from automobiles, e.g. foam, textile, rubber, and tires. The chosen acoustic parameters—sound absorption coefficient and sound transmission loss—of these materials were tested, and the acoustic properties of materials were subsequently improved compared to tested values and potential applications for them were found.

Keywords: noise; transportation; sound absorption coefficient; sound reduction index

1. Introduction

The negative effects of environmental noise are various and can be caused by many different sources of noise. According to EU directive 70/157/eec [1] and the World Health Organization (WHO) [2], there are approximately 80 million people in the European Union exposed to high noise levels. It is unacceptable in the long term. There are 170 million people living in so-called "gray areas" that are characterized by the permanent production of annoying noise [3–5].

The significant source of noise is transport (road, rail and air) while the dominant source is road traffic [6,7]. The problem of road traffic noise is often tackled through the construction of noise barriers [7–9] from various absorbing and reflective materials. There are several research teams dealing with the research of acoustic materials [9–11].

This paper presents the results of scientific and research activities focusing on the development and study of acoustically suitable materials based on recycled components from vehicles after the expiry of their life cycle [12–14]. The results obtained by measuring selected acoustic parameters (the sound absorption coefficient (α) and the reduction index R) are presented [15,16].

2. Measurement of Selected Acoustic Parameters of the Acoustic Materials under Development

The following acoustic parameters were chosen from several possible acoustic descriptors:

- the reduction index R; and
- the sound absorption coefficient (α).

The sound absorption coefficient (α) and the reduction index R can be measured by two methods:

- the standing wave ratio method; and
- the transfer function method.

The transfer function measurement method was utilized. This method can be used for measuring the sound absorption coefficient, the reflection factor, the normal impedance and the normal admittance [17–20].

Figure 1 shows an impedance tube based on the transfer function method.

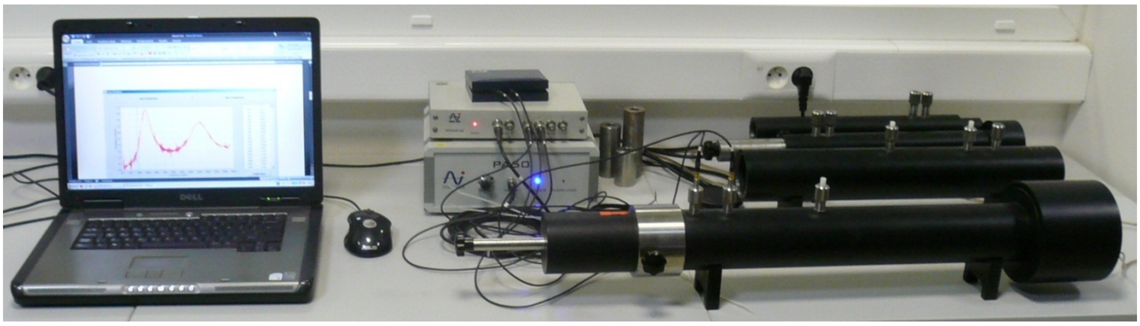

Figure 1. Kundt tube.

The proposed measuring methodology includes the utilization of a Kundt tube with two positions of the positioning microphones and the system of numerical frequency analysis for the determination of normal incidence sound absorption coefficient of sound absorbers. It can be applied for the determination of the acoustic surface impedance or acoustic surface admittance for the sound absorbing materials. The impedance ratios of sound absorbing materials are proportional to their physical properties, such as airflow resistance, elasticity, porosity and density.

In compliance with STN EN ISO 10534-1 standard, the proposed test method utilizes an impedance tube with a sound source connected to one end and a test specimen mounted in the tube on the other end. This test method is an alternative measurement method, which is, in general, much faster than the method included in STN EN ISO 10534-1 [21–24].

The measurement of the absolute and transmission characteristics of the developed acoustic materials are used by researchers for the acoustic design of devices such as automobiles, household appliances, etc.

3. Measurement of Chosen Acoustic Parameters of Developed Acoustically Suitable Materials

The proposed measurement methodology was verified by experimental tests with newly developed materials (Ekomolitan and recycled rubber). The experimental tests included the measurements of acoustic parameters, namely the sound absorption coefficient (α) and the reduction index R for the tested materials.

The experimental research tests were designed and verified at the Department of Process and Environmental Engineering, Faculty of Mechanical Engineering, Technical University of Kosice, Kosice, Slovakia.

3.1. The Hardware and Software Equipment Used

The architecture of hardware equipment used for measuring the sound absorption coefficient (α) (for the frequency bands 100–800 Hz and 400–2500 Hz) is shown in Figure 2.

The measured system includes the tube with the inner diameter of 60 mm (marked as SW060-L) and the holder of the tested sample with the inner diameter of 60 mm (marked as SW060-S).

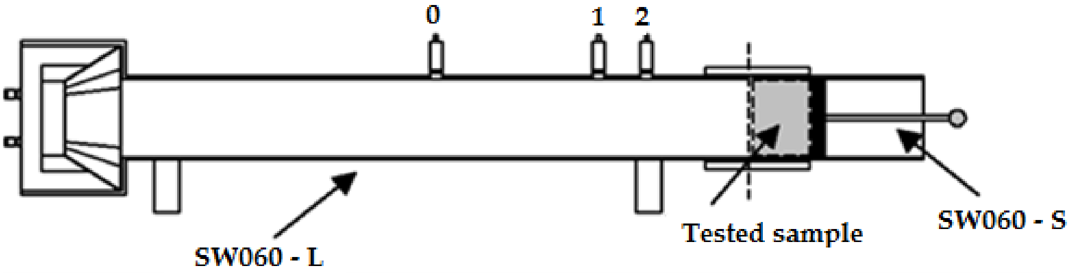

Figure 2. The sound absorption coefficient (α) system measured: 0, 1, and 2 are the mounting places for microphone sockets.

The system for measuring of the reduction index R (for the frequency bands 100–800 Hz and 400–2500 Hz) is shown in Figure 3. Similarly, the measured system consists of the tube with the inner diameter of 60 mm (marked as SW060-L) and of the tube extension piece with the inner diameter of 60 mm (marked as SW060-E).

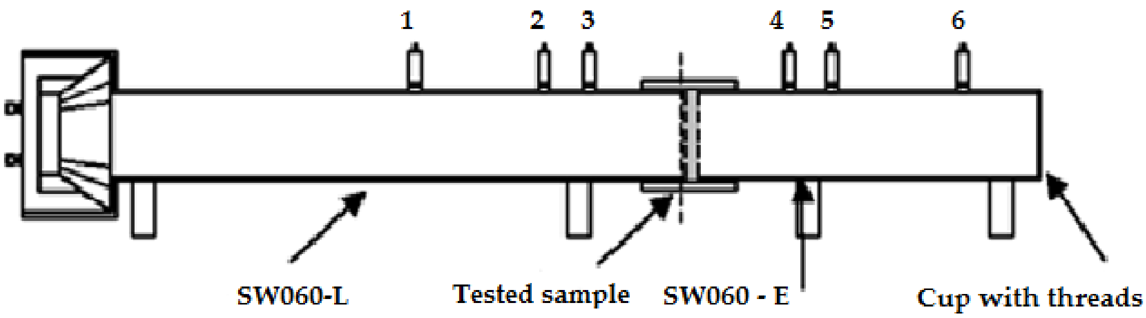

Figure 3. The reduction index R system measured: 0, 1, 2, 3, 4, and 5 are the mounting places for microphone sockets.

3.2. The Experimental Materials Used in Testing

For experimental measurements, materials from selected components of vehicles after the expiry of their life cycle were used. Materials tested were recycled by operations such as crushing, cutting, grinding, heating, stamping, etc.

Specifically, the following materials were used.

- **Ekomolitan** (Figures 4 and 5): The material was manufactured by the recycling of a pure polyurethane foam (PUR foam) from seats taken from old vehicles by adhesive-free hot pressing of the recycled PUR products technology:
  - ○ Ground fraction: 2.00–10 mm;
  - ○ Pressing at 200 °C (Steaming by superheated steam);
  - ○ Pressing pressure: 5.7 kPa;
  - ○ Hold time under the pressure at given temperature: 12 min;
  - ○ Pressed piece density: 1.2 g·cm^{-3}

Figure 4 shows the specimens of the PUR foam ground fraction. Figure 5 shows the result after pressing, i.e., Ekomolitan foam.

Figure 4. Ground fraction of PUR foam.

Figure 5. Ekomolitan after pressing.

- **Recycled rubber** (Figures 6 and 7): It is the product of the process of recycling used tires. To produce sound-absorbing material, the rubber sawdust, rubber cords and rubber grinding layer from tire retreading is suitable. The mono-structural material is most often produced from a rubber fraction. The technical material selected:
  - Ground fraction: 4–6 mm;
  - Pressing temperature: 900–1200 °C;
  - pressing pressure: 20.265 bar = 2.0265 MPa;
  - Hold time under the pressure at given temperature: 12–15 min;
  - Pressed piece density: 1.65 g·cm^{-3}

The author of this paper filed patent application No. 1/288237 [8] dealing with the production of this sound-absorbing material.

Figure 6. Ground Fraction of Recycled Rubber.

Figure 7. Recycled rubber after pressing.

- **Nobasil** (Figure 8): Material was manufactured from mineral fibers (bead wool) bonded by a modified artificial resin with the addition of hydrophobic and antifungal substances. The material is sewn on one side by glass thread with stitches fastened with glue onto a lightweight glass fiber mat.

Figure 8. Nobasil from mineral fibers.

This material has wide application in civil engineering owing to its good thermal-insulation and sound-absorbing properties. The material has been used in comparisons with newly developed material properties. Nobasil is often used as one of the materials in noise barrier sandwich construction.

3.3. Preparation of Test Samples

Three materials, including their combinations, were used for the preparation of the test samples (Ekomolitan, recycled rubber and Nobasil). The specific examples are shown in Figure 9.

The test samples had diameters of 30 mm and 60 mm. The samples had thicknesses of 20 mm, 30 mm, 40 mm, 50 mm and 60 mm.

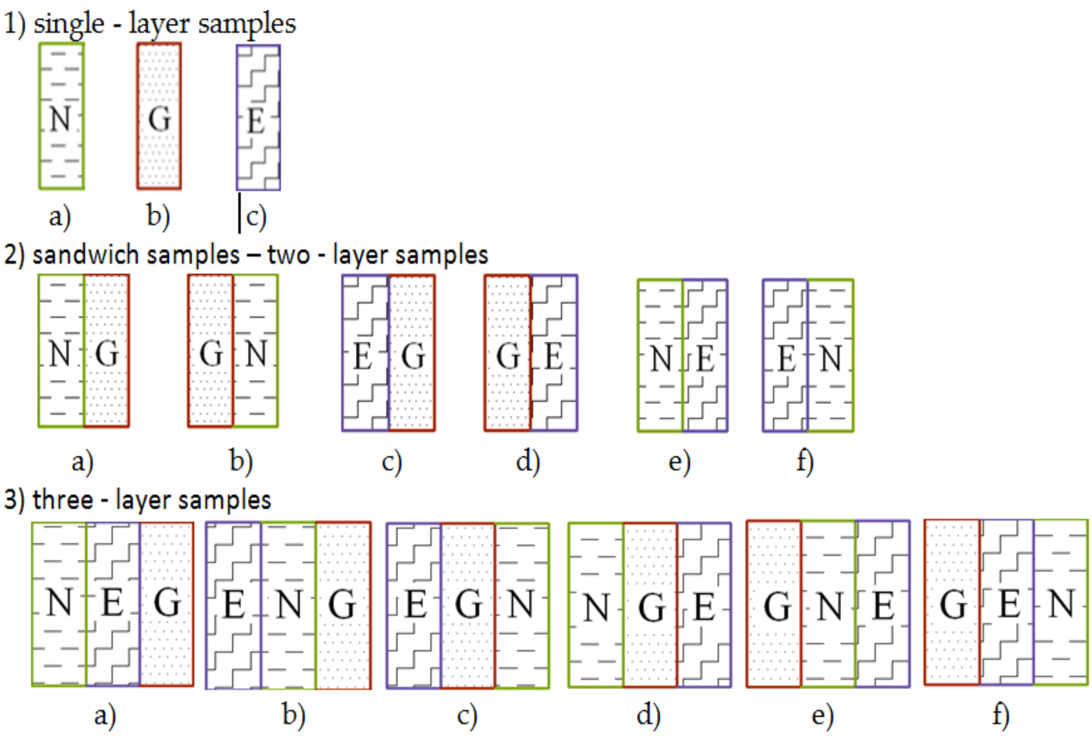

Figure 9. Test samples: N—Nobasil; E—Ekomolitan; G—Recycled Rubber.

4. The Results of Experimental Measurements

The sound absorption coefficient (α) is a dimensionless number ranging from 0 to 1. The closer the measured value is to 1 (or if it is equal to 1), the better (higher) is the sound absorption of the measured material (absorber).

The reduction index R was also measured in the experiment. This is the value given in "dB" based on the ratio of the wave of incident sound to the front side of the acoustically absorbing material to the sound waves transmitted from the rear side. The reduction index R represents the damping properties of the material, i.e., the is higher value, the more muffled is the sound.

Many measurements of the sound absorption coefficient (α) and reduction index R were made for homogeneous material (Ekomolitan, recycled rubber, or Nobasil) and for two- and three-layered sandwich structures with various thickness.

The values obtained for the sound absorption coefficients of the materials with a thickness of 60 mm are given in Table 1, where red numbers mean the worst values of the parameters obtained from the materials measured and green numbers mean the best values of the parameters obtained from materials measured.

The reduction index R values for materials with thickness of 60 mm are shown in Table 2, where red numbers mean the worst values of the parameters obtained from materials measured and green numbers mean the best values of the parameters obtained from the materials measured.

The values for materials with thickness of 20 mm, 30 mm, 40 mm, and 50 mm [9] were obtained similarly.

The results of measurements of the sound absorption (α) of the homogeneous material (Ekomolitan, recycled rubber, and Nobasil) with thickness of 60 mm are shown in Figure 10.

The results of the reduction index R measurements of 60-mm-thick homogeneous materials are shown in Figure 11.

Table 1. Sound absorption coefficient values for materials with thickness of 60 mm.

	The Sound Absorption Coefficient α [-]								
Frequency f [Hz]	**Ekomolitan**	**Recycled Rubber**	**Nobasil**	**Recycled Rubber + Ekomolitan + Nobasil**	**Recycled Rubber + Nobasil + Ekomolitan**	**Nobasil + Recycled Rubber + Ekomolitan**	**Ekomolitan + Recycled Rubber + Nobasil**	**Ekomolitan + Nobasil + Recycled Rubber**	**Nobasil + Ekomolitan + Recycled Rubber**
100	0.099	0.057	0.242	0.154	0.191	0.212	0.057	0.113	0.179
125	0.154	0.081	0.277	0.185	0.226	0.212	0.159	0.154	0.217
160	0.256	0.106	0.316	0.295	0.308	0.285	0.219	0.217	0.272
200	0.361	0.16	0.361	0.409	0.39	0.341	0.299	0.273	0.333
250	0.404	0.23	0.393	0.553	0.469	0.385	0.406	0.344	0.387
315	0.654	0.344	0.42	0.686	0.537	0.427	0.507	0.402	0.433
400	0.804	0.498	0.461	0.757	0.592	0.456	0.671	0.547	0.474
500	0.873	0.618	0.494	0.786	0.622	0.469	0.716	0.624	0.505
630	0.891	0.643	0.527	0.715	0.673	0.495	0.741	0.704	0.551
800	0.861	0.562	0.567	0.609	0.649	0.479	0.693	0.777	0.567
1000	0.818	0.464	0.603	0.515	0.612	0.506	0.672	0.841	0.648
1250	0.789	0.445	0.636	0.445	0.549	0.625	0.689	0.872	0.628
1600	0.801	0.519	0.663	0.381	0.472	0.718	0.779	0.931	0.654
2000	0.849	0.51	0.689	0.354	0.397	0.724	0.898	0.96	0.693
2500	0.873	0.425	0.7	0.369	0.387	0.727	0.985	0.972	0.716
3150	0.873	0.542	0.739	0.491	0.463	0.763	0.989	0.957	0.782
4000	0.889	0.52	0.791	0.652	0.616	0.805	0.947	0.932	0.813
5000	0.902	0.615	0.795	0.625	0.645	0.833	0.928	0.932	0.84
6300	0.923	0.626	0.83	0.564	0.568	0.853	0.929	0.966	0.862

Table 2. Reduction index R values for materials with thickness of 60 mm.

	Reduction Index R [dB]								
Frequency f [Hz]	**Ekomolitan**	**Recycled Rubber**	**Nobasil**	**Recycled Rubber + Ekomolitan + Nobasil**	**Recycled Rubber + Nobasil + Ekomolitan**	**Nobasil + Recycled Rubber + Ekomolitan**	**Ekomolitan + Recycled Rubber + Nobasil**	**Ekomolitan + Nobasil + Recycled Rubber**	**Nobasil + Ekomolitan + Recycled Rubber**
100	6.451	12.018	19.971	14.265	14.311	14.399	14.119	14.345	14.219
125	6.800	12.245	19.928	14.278	14.240	14.481	14.113	14.392	14.166
160	7.330	12.513	20.192	14.301	14.315	14.567	14.213	14.44	14.208
200	7.853	12.812	20.700	14.401	14.410	14.382	14.347	14.516	14.259
250	6.160	13.159	21.367	14.505	14.094	14.554	14.493	14.626	14.337
315	7.387	13.557	22.379	14.870	14.347	14.786	14.387	14.825	14.583
400	7.932	13.971	23.834	15.543	14.626	15.123	14.723	14.421	15.257
500	8.533	14.059	24.815	15.845	14.816	15.324	15.086	14.744	15.375
630	9.058	13.803	26.876	17.060	14.991	15.45	15.642	14.825	16.075
800	9.721	13.554	29.309	19.336	16.151	16.526	16.893	15.901	17.932
1000	10.748	13.027	31.910	21.458	18.201	18.101	16.220	16.931	17.652
1250	11.896	13.448	34.956	21.515	16.690	15.048	17.916	18.142	21.949
1600	13.270	15.061	38.039	25.195	21.604	20.000	20.140	21.307	24.455
2000	14.703	16.24	28.289	26.901	24.655	23.068	21.898	23.629	26.307
2500	16.513	15.888	30.917	29.377	27.707	25.496	25.671	27.451	28.086
3150	18.585	17.441	14.019	32.164	31.809	29.595	29.266	31.334	29.326
4000	21.221	18.817	30.334	33.088	32.173	30.934	31.729	31.536	30.796
5000	23.828	21.204	26.772	36.395	36.148	34.958	36.218	35.653	35.193
6300	26.176	28.336	42.359	43.245	40.895	38.906	27.802	37.467	39.318

Measurements of sound absorption coefficients (a) and reduction index R of sandwich absorbents consisting of different combinations of two (with thickness of 20 mm, 40 mm and 60 mm) and three (with thickness of 30 mm and 60 mm) materials (Ekomolitan, recycled rubber, Nobasil) were also obtained. The sandwich structures are applicable for noise barrier construction (shields). The results of measurements in the frequency band ranging from 500 Hz to 1500 Hz are presented in Figures 12 and 13.

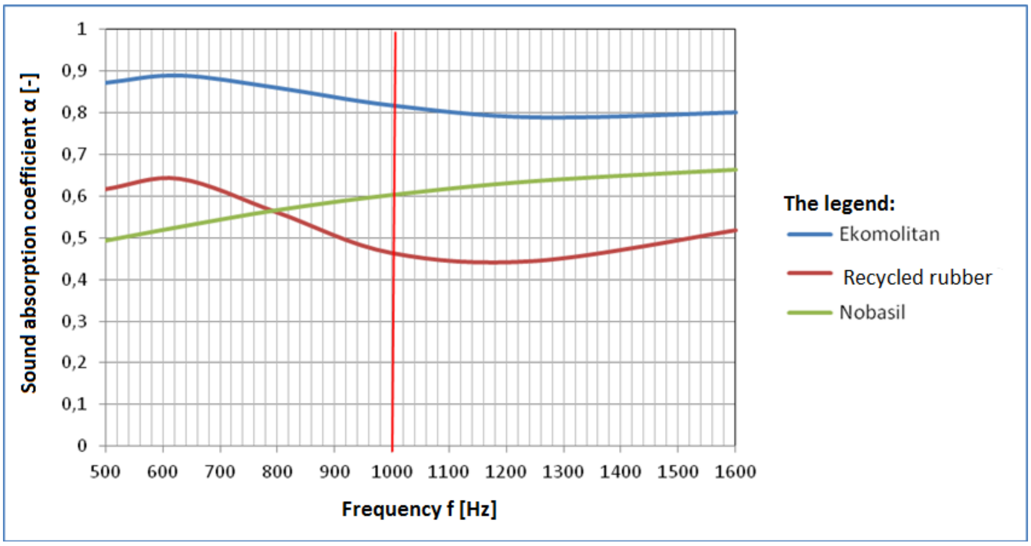

Figure 10. Sound absorption coefficient α (material thickness—60 mm).

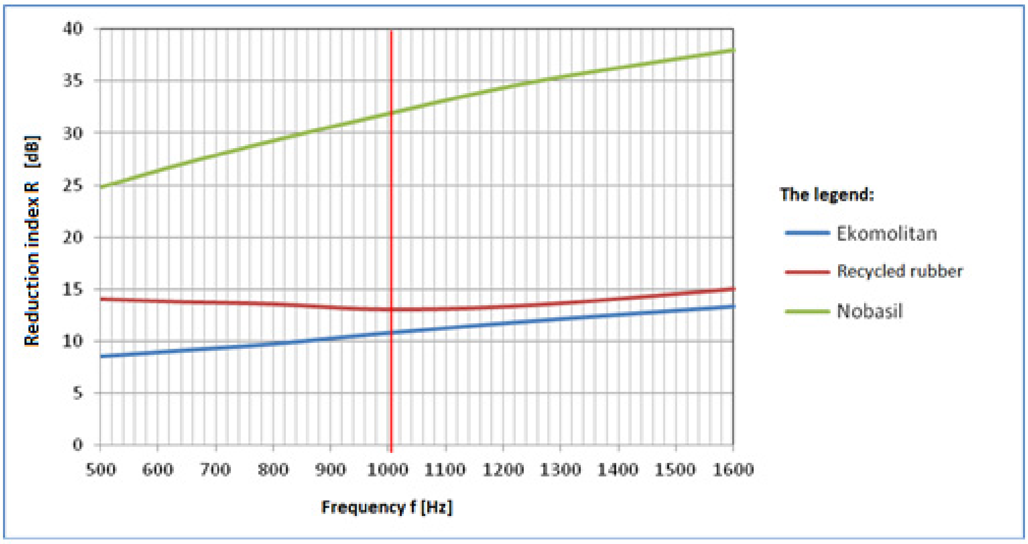

Figure 11. Reduction index R (material thickness—60 mm).

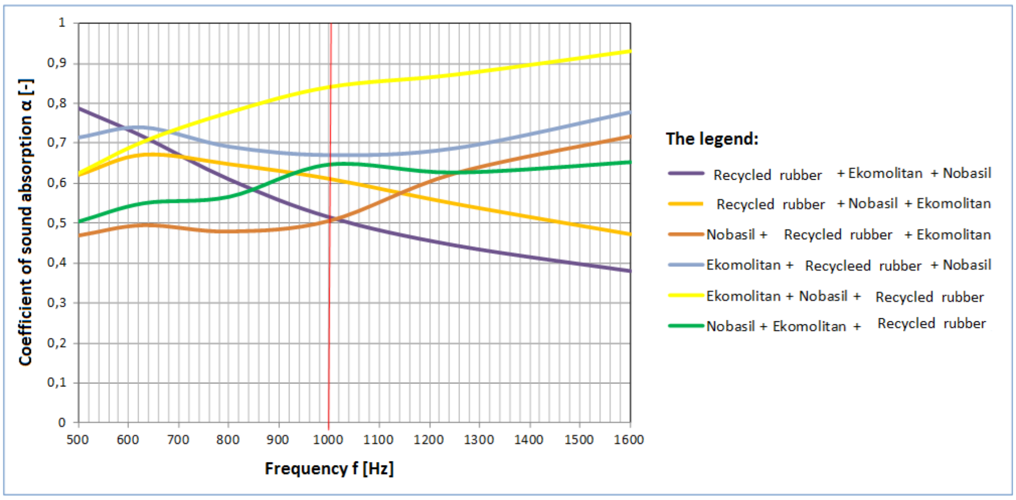

Figure 12. Sound absorption coefficient of three-layered sandwiches (total thickness of sandwiches—60 mm).

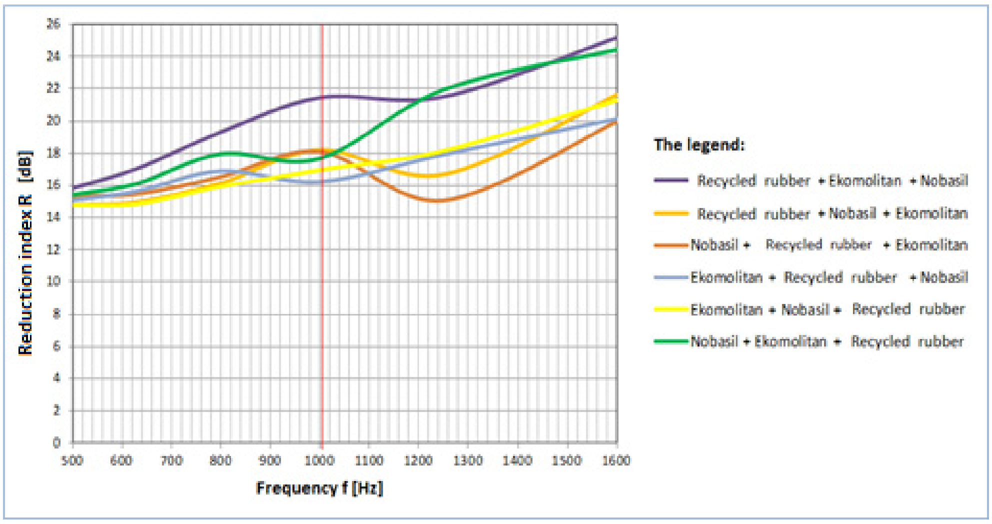

Figure 13. Reduction index R of two-layered sandwich absorbers (material thickness—60 mm).

5. Conclusions

The frequency spectrum maximum of traffic noise ranges from 500 Hz to 1500 Hz, with the loudest noise produced by frequency of 1000 Hz. Based on the measured sound absorption coefficient (α) values of the materials tested (Ekomolitan, recycled rubber and Nobasil) of different thicknesses (20 mm, 30 mm, 40 mm, 50 mm and 60 mm) at frequencies ranging from 500 Hz to 1500 Hz, and especially at frequency of 1000 Hz, Nobasil appears to be the most suitable material at a thickness of $\geq$20 mm, followed by Ekomolitan and finally recycled rubber. The Ekomolitan appears to be the most suitable materials at thickness of $\geq$ 20 mm followed by Nobasil, and finally recycled rubber.

It is obvious from the measured values of the sandwich absorbers' sound absorption coefficient (α) that the order of sandwich layers (of materials used) is important. The recommended order of sandwich (absorber) layers from the noise source at the measured materials is as follows:

(a) Two-layered sandwiches:

- Ekomolitan + Nobasil;
- Ekomolitan + Recycled rubber; and
- Recycled rubber + Nobasil.

(b) Three-layered sandwiches:

- Ekomolitan + Nobasil + Recycled rubber.

It was established that, based on the measured values of reduction index R of the tested materials under consideration (Ekomolitan, recycled rubber and Nobasil), for different thicknesses (20 mm, 30 mm, 40 mm, 50 mm and 60 mm) and frequencies ranging from 500 Hz to 1500 Hz, the best results, for all measured thicknesses of materials, were obtained with Nobasil, followed by recycled rubber and Ekomolitan.

Based on the measured values of reduction index R of sandwich absorbents, it is important to state the importance of the order of individual layers of materials used in the sandwich. Note that the order of the individual layers of used sandwich materials is important. The recommended order of the sandwich (absorber) layers from the noise source of the measured materials is as follows:

(a) Two-layered sandwiches:

- Recycled rubber + Nobasil;
- Recycled rubber + Ekomolitan; and
- Nobasil + Ekomolitan.

(b) Three-layered sandwiches:

- Recycled rubber + Ekomolitan + Nobasil.

The experimental measurements have demonstrated the suitability of selected materials (PUR foam and recycled material from tire) extracted from cars after the expiry of their life cycle in the noise barrier (shield) sandwich constructions to minimize traffic noise in the environment.

Author Contributions: B.M. responses for the scientific-research content of the article. S.L. is responsible for the correspondence, realization and preparation of an experimental part. B.A. realised and evaluated the results of the experiments. M.M. is responsible for the preparing of the tested samples and references. M.A. processed the graphic pages of the article.

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Conflicts of Interest: The authors declare no conflict of interest.

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