The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM)
ISSN: 2602-3199

The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 2024

Volume 32, Pages 379-388

IConTES 2024: International Conference on Technology, Engineering and Science

Experimental Study of Acoustical Properties of Recycled Rubber Panels

Yonka Ivanova
Sofia University "St. Kliment Ohridski"

Todor Partalin
Sofia University "St. Kliment Ohridski"

Abstract: This paper is focused on the characterization of multilayer acoustic panels made from recycled rubber waste produced by the Zebra factory in Bulgaria. The acoustical characteristics of rubber samples as well as three-layer panels were investigated to determine their applications as sound barriers or resilient flooring. The experiments to determine the sound absorption and sound reflection coefficients were carried out in laboratory conditions using the standing wave method in the frequency range from 100 to 2000 Hz. The potential of recycled materials to reduce airborne and impact noise was investigated and discussed. The sound insulation coefficients of recycled rubber panels were determined by the "two-chamber" method in the frequency range from 100 to 4000 Hz. For this purpose, small acoustic chambers were constructed and tested. The dynamic properties (dynamic stiffness and damping ratio) of the experimental materials were also investigated by an impact test. The obtained results have been discussed and analyzed with a view to evaluating the possibilities of application as acoustic barriers and flooring.

Keywords: Recycled rubber panel, Sound absorption, Sound insulation, Dynamic stiffness

Introduction

In recent years, the automotive industry has produced about 1.5 billion waste tires worldwide every year (Balmori et al., 2024; Presti et al., 2013; Martin et al., 2014; Valentini et al., 2022). Used tires accumulate and pollute the environment. An alternative solution to reduce used tires is to transform them through recycling and their subsequent application. Rubber granulate can be used for various applications in the production of elastomers, replacement of filler materials, panels with good sound and thermal insulation properties, resilient flooring and many other applications in civil construction (Balmori et al., 2024; Schiavoni et al., 2016; Kumar et al., 2020; Benkreira et al., 2011).

Recently, there has been a growing interest in the study of the properties of waste rubber materials and their appropriate application (Asdrubali et al., 2008; Medina et al., 2018; Nuzaimah et al., 2018; Balmori et al., 2024; Vilniškis et al., 2024). Despite the already published results about sound-absorbing and noise-insulating properties, the topic is relevant in view of the development of new materials from recycled rubber in the form of panels, partitions, elastic pads.

The aim of the present study is to investigate the properties such as sound absorption and reflection coefficient, sound insulation and dynamic stiffness of materials, made out of rubber crumbs.

Experimental Procedure

Materials

- Selection and peer-review under responsibility of the Organizing Committee of the Conference

The object of investigation is the operational properties of recycled rubber products produced by the company Zebra AD, Sofia. The rubber panels are made from rubber granules of irregular shape and sizes from 2 to 5 mm, adhesive and a sheet of styrene butadiene rubber (SBR) with a thickness of 3 mm by pressing. Table 1 shows the materials from which five samples were made with the shape and dimensions required for the measurement. Comparative samples of Ethylene vinyl acetate (EVA)-Expanded Rubber with a density of 50 kg/m3 are also used in the research. The acoustic properties of double panels made of SBR rubber and two samples of rubber granules are also investigated.

Table 1. Materials

Material	Code	Density, kg/m3	Thickness, m
SBR+Rubber granules plate		1180	0.019
SBR+Rubber granules+SBR	SBR+M+SBR	1230	0.022

The methodology of experiments is consisted of the following steps:

Study of sound absorption and reflection coefficients;
Study of sound insulation and impact sound reduction by small-sized acoustic chambers;
Study of dynamic stiffness.

Sound Absorption Research Methodology

Investigation of the sound absorption and reflection properties of rubber panels was carried out in the impedance tube in laboratory conditions. The experimental setup consists of impedance tube with a diameter of 90 mm, a loudspeaker, a sound generator, PC based Real Time Analyzer and Sound Level Meter System, a microphone and Multi-Instrument Software. The testing equipment according to the standard EN ISO 10534-1 is presented in Figure 1.

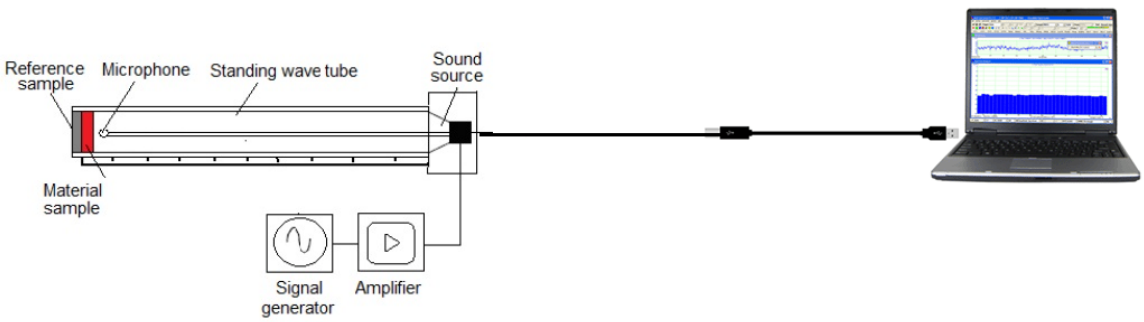


Figure 1. Schematic experimental setup of sound absorption and reflection measurement

The loudspeaker, which is located at one end of the tube, was induced by signal generator that generates sine waves in the frequency range from 100 to 2000 Hz. According to physical theory, the waves propagating in the tube to the other end and are reflected at the hard termination end cap made from brass material. The rubber samples are placed on the rigid end cap. The phase interference between the waves in the pipe which are incident upon and reflected from the test sample results in the formation of standing waves. The pressure amplitudes at nodes and antinodes are measured with a microphone probe which slides along a ruler. The ratio of the pressure maximum (antinode) to the pressure minimum (node) is called the standing wave ratio (SWR).

$$SWR = \frac{p_{rms,max}}{p_{rms,min}} \quad (1)$$

This ratio is used to determine the sample's reflection coefficient R and absorption coefficient α. Sound power reflection coefficient Rp can be expressed by

$$R_P = \beta = \left|\frac{SWR-1}{SWR+1}\right|^2 \quad (2)$$

The sound absorption coefficient α at a given resonance frequency is calculated by EN ISO 10534-1.

$$\alpha = 1 - R_p \tag{3}$$

$$\alpha = \frac{4SWR}{(SWR+1)^2} \tag{4}$$

Measurements in the frequency range were performed five times on each sample, which was glued and firmly attached to the pipe wall.

Methodology of Sound Insulation Measurement

Laboratory equipment for the evaluation of airborne and impact noise reduction must meet the requirements of the standards EN 16283, which requires the presence of a reverberation chamber with a volume of more than 10 m^3. For research purposes, many researchers have developed and used miniature acoustic boxes with a camera for the sound source and a camera to receive the transmitted sound (Godinho et al., 2010; Branco et al., 2010; Pleban et al., 2018; Kim et al., 2011:;Reddi et al.,2020; Wen et al., 2019). These non-standardized testing systems have been used to analyze and to compare the sound insulation of walls, partitions, and also initial evaluation of the impact noise of elastic layers (Rushforth et al., 2005).

To determine the sound insulation capacity of the experimental materials, the two-room method (Fahy, 2000; Isaac et al., 2020; Prato et al., 2013; ElSaeed et al., 2019). Has been applied. For the purpose of current investigation, a small acoustic box has been built especially for the tested materials. The use of small chambers does not follow the standards, but allows receiving the evaluation of sound insulation potential of the some materials. The testing in certain laboratory conditions can be reduced lateral sound transmissions from the test plate. Due to the small size, the system is expected to provide better results at mid and high frequencies.

The developed reduced acoustic box consists of two chambers. The chamber in which the sound source is located is a reverberation type and has dimensions of 700x600x600 mm. This chamber is built from the outside in from plasterboard, chipboard, mineral wool and glass panels. The glass walls on the inside form a five-sided box without parallel walls. Two full-range speakers with a frequency range of 20Hz to 20,000Hz are installed in the source chamber.

The receiving chamber is anechoic type with dimensions of 700x600x500 mm. It is made of chipboard, mineral wool and two insulation layers of foam and noise-absorbing pyramid-type foam. Between the two chambers there is a frame with an opening for mounting the examined specimens. Measurement microphones have a frequency range of 20Hz to 20,000Hz and are mounted in both cameras.

The differences in sound pressure levels of the sound waves in the source room and receiving room are recorded by a two-channel acoustic analyzer in real time by means of a special control and measurement software Multi Instrument 3.9 Proffessional. The sound transmission outside the experimental setup is minimized. Figure 2 shows a schematic of the small acoustic chambers used for sound insulation study.

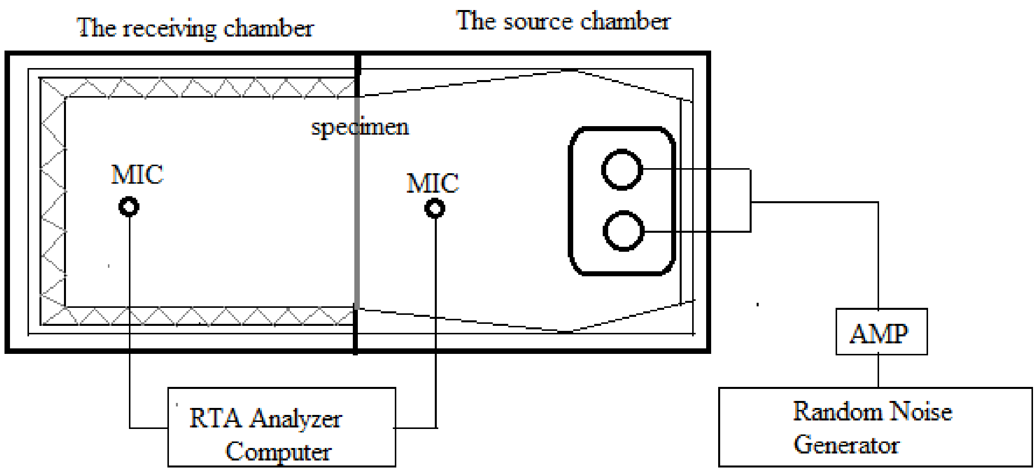


Figure 2. Schematic experimental setup of small-sized acoustic chambers.

Study of Dynamic Stiffness of Recycled Rubber Materials

The resilient materials such as recycled rubber are used in constructions called "floating floors". The effectiveness of the floating floors depends on the mechanical properties of the insulation layers (Belli et al.,2003; Schiavi et al., 2007; Schiavi et al., 2015). Dynamic stiffness is one of important properties impact sound insulation materials. The measurement method for the determination of dynamic stiffness is defined in EN 29052-1. A mass representative for typical floating floors is used to impose a static load on the tested specimen. The mass is excited by impact hammer and from the resonance frequency of this spring-mass system, the dynamic stiffness (s') is calculated with the relation:

$$s' = (2\pi f_r)^2 . m \tag{5}$$

Where m is the mass per unit area of the loading plate (200 kg/m^2), f_r is the resonance frequency in Hz. Another important property of elastic layers is internal damping. The resonant frequency curve carries this information. Using the half-power point method, it is possible to estimate the internal damping ratio δ and quality factor Q.

$$Q = \frac{f_0}{f_2 - f_1} = \frac{f_0}{\Delta f} = \frac{1}{2\delta} \tag{6}$$

Where the frequencies f_1 and f_2 are these frequency values, where the acceleration level has decreased by 3 dB.

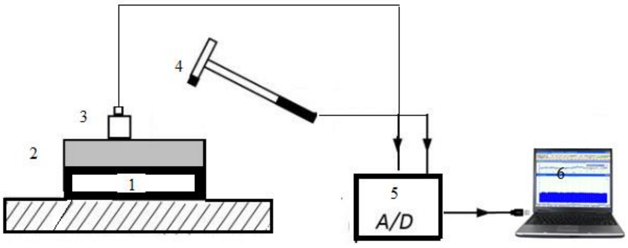
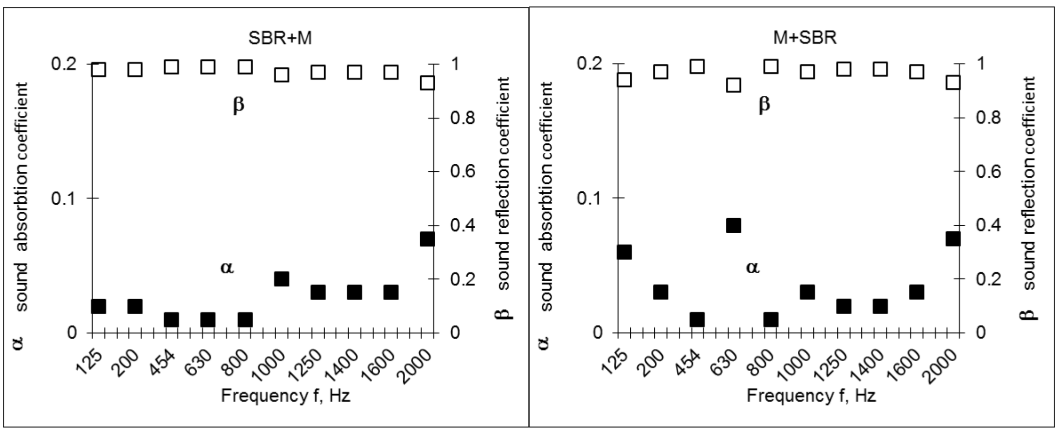


Figure 3. Schematic experimental setup for measuring the dynamic stiffness: 1) the rubber test specimen; 2) the upper steel plate; 3) the accelerometer (CA-YD-160); 4) the impact hammer (LC-01KE); 5) the data acquisition card (VT IEPE-2G05) and 6) the PC.

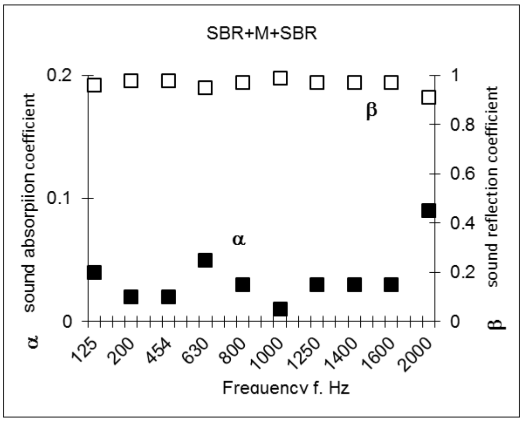
Results and Discussion

Results of Sound Absorption Measurement

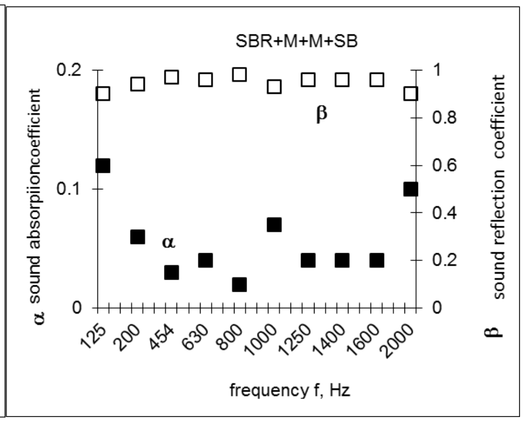
Figure 4 shows the sound absorption and reflection coefficients vs. frequency for the tested materials. Figure 4a presents the test results of SBR+M sample, with the sound-reflecting surface being the smooth SBR rubber side. Figure 4 b gives results from the same specimen, with the sound-reflecting surface being the rough side of the recycled rubber granules plate. Figure 4c shows the sound absorption and reflection for a 22 mm thick SBR+rubber granule plate+ SBR panel. Figure 4d shows the results of an examination of a panel made of SBR, two plates of rubber granules and SBR with a total thickness of 28 mm.



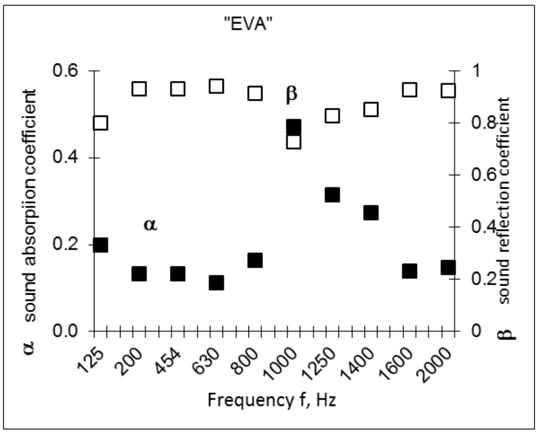
a) b)



c)



d)



e)

Figure 4. Sound absorption and sound reflection for different waste materials:
a – SBR+M; b – M+SBR; c- SBR+M+SBR; d- SBR+M+M+SBR; e- EVA sample

It can be observed that the values of the sound absorption coefficients are low throughout the frequency range of the study, with average values below 0,1. The relatively high density and pore-free test samples show a high sound reflection coefficient of about 0,9. Figure 4 e) shows the results of a comparison sample type "EVA" with a thickness of 26 mm and a density of 50 kg/m^3. The average value of the sound absorption coefficient is about 0,4. It can be seen that at some frequencies the coefficient increases. The results can be explained by the closed cell surface structure with high sound impedance and high sound reflection. (Segura, et al., 2015).

Results of Sound Insulation Measurement

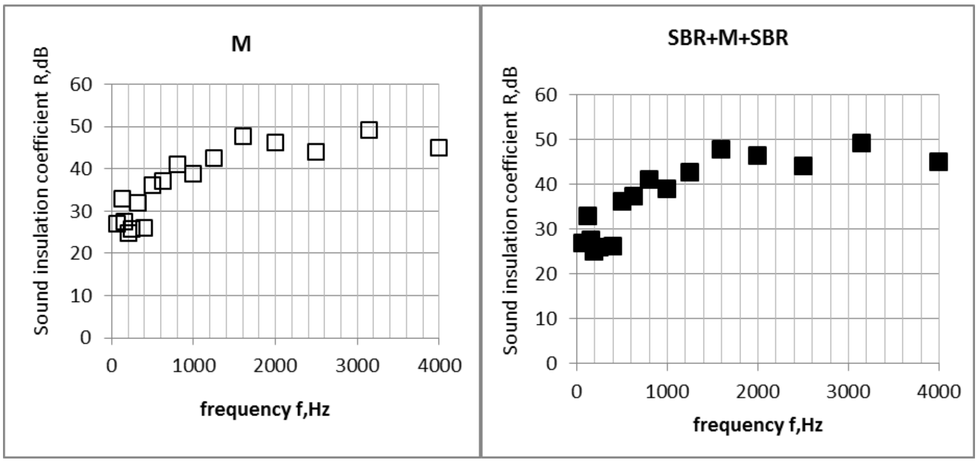
The sound insulation coefficient has been determined using the two small acoustics chambers between which a test specimen is placed. The test samples are recycled rubber plates with dimensions of 500x500 mm and different thicknesses. The mode of operation is stationary. The following conditions have been maintained during the measurements: the distance between the source and the microphone is greater than 0.5 m; the measurement time is greater than 120 s; white noise is used as a sound signal; the level of the emitted sound signal is 100 dB.

The determination of sound insulation coefficient of the experimental samples consists of making measurements of the sound pressure levels in the source chamber and in the receiving chamber, followed by a calculation of the difference between the two values. The emitted and received signals and their frequency characteristics have been monitored using an oscilloscope, and the analysis has been performed in one-third octave frequencies. The sound insulation coefficient R is calculated using the relationship:

$$R = Lp_1 - Lp_2 \quad (7)$$

Where Lp_1 is the average sound pressure level in the source chamber, Lp_2 is the average sound pressure level in the receiving chamber.

The results of the measurements carried out for the rubber plates are averaged and given in Figure 5. Figure 5a shows the results of the sound insulation coefficients when testing a rubber granules plate, and Figure 5b -the results of the meadurement of a SBR+M+SBR panel.



a) b)

Figure 5. Sound insulation coefficients vs. frequency

a) Recycled rubber granules specimen; b) Panel SBR+M+SBR

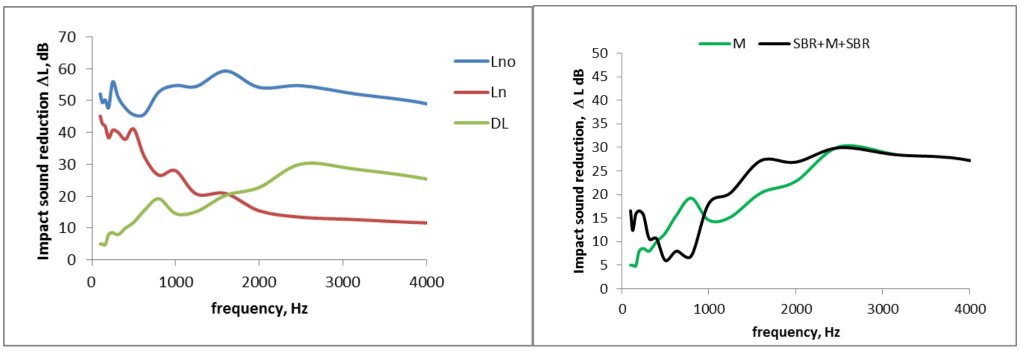
It can be noted that the average sound insulation coefficients for the studied recycled rubber samples (M), as well as for the panels made with the addition of rubber sheet (SBR+M+SBR), are about 38 dB in the studied frequency range up to 4000 Hz. The products could be used for soundproofing walls, ceilings and floors.

Results of Impact Sound Reduction

The measurements of the impact sound reduction have been performed in the described small-sized acoustic chambers. A metal ball weighing 0.5 kg was used as the impact source dropping from a height of 40 mm. The floor was not a concrete slab, but chipboard with a thickness of 20 mm. The impact sound pressure level resulting from the installation of a chipboard floor has been determined. A panel of recycled rubber is then added to the chipboard and the impact sound pressure level resulting from the placement of the tested flooring is measured. The defined characteristic is the improvement in impact sound insulation, ΔL, defined as the reduction in normalized impact sound pressure level resulting from the placement of the tested flooring.

$$\Delta L = L_{no} - L_n \tag{8}$$

Where L_{n0} is the normalized sound pressure level when hitting a floor without a rubber coating and Ln is the normalized sound pressure level upon impact on the floor with rubber coating. The results of the ΔL, in decibels are given in the Figure 6. It can be seen that the impact noise reduction at frequencies from 1000 to 4000 Hz averages about 22-23 dB for the rubber crumbs plate and SBR+M+SBR panel.



a) b)

Figure 6. Impact sound reduction vs. frequency

a) sound pressure levels without a rubber, with recycled rubber plate and impact sound reduction;

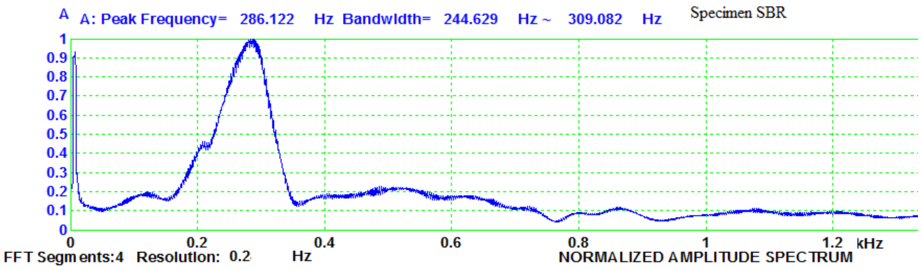
b) impact sound reduction for rubber crumbs plate M and panel SBR+M+SBR

Results of Dynamic Stiffness Measurement

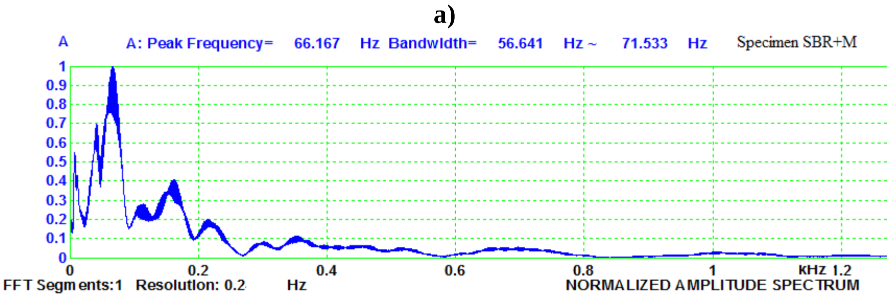
The measurements of the dynamic hardness of the recycled rubber samples are performed by setup, shown in the Figure 3. The test specimens are cylindrical with the same diameter of 90 mm and different thicknesses as shown in Table 2. They are placed on a main solid steel plate weighing 30 kg. The loading steel plate weighs 1.2 kg, so the reduced loading mass is 200 kg/m^2.The accelerometer is glued in the center of the steel plate. Excitation is by an impact modal hammer with a stiff tip. A signal from the accelerometer is recorded after the excitation is applied. The chosen frequency resolution is $\Delta f = 0.2$ Hz.

The frequency analyzer allows us to identify the resonant frequency of the mass-spring system, consisting of the load plate and the elastic material. The widths of the resonance curve at a level 3 dB from the maximum of the resonance peak, necessary for the calculation of the quality factor and damping ratio, have been also determined. On each sample, 5 recordings were made for 20 seconds and the resonance curves have been obtained.

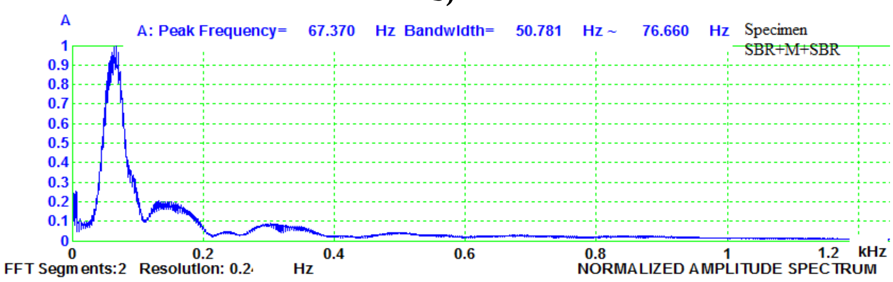
The results are averaged and shown in Table 2. Figure 7 present frequency resonance curves of tested samples: a- test sample SBR rubber sheet with a thickness of 3 mm; b- test sample recycled rubber from rubber crumbs and tightly glued rubber sheet SBR; 3- panel obtained from SBR+M+SBR; 4- SBR+M+M+SBR; 5- test specimen is EVA type porous rubber. The dynamic stiffness was calculated according to (5), and quality factor and damping ratio - according to (6).



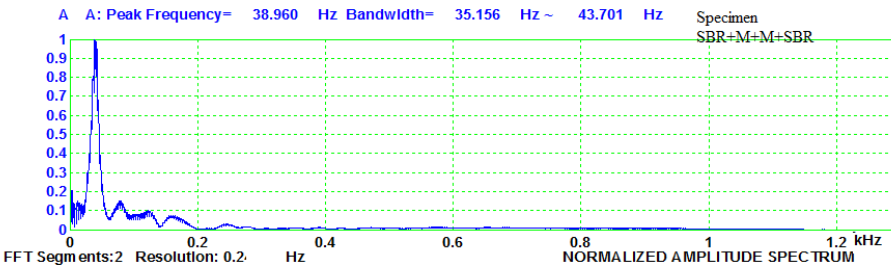
a)



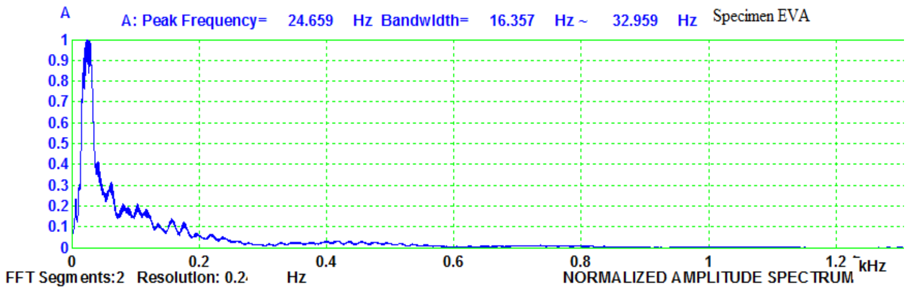
b)



c)



d)



e)

Figure 7. Frequency resonance curves of tested materials:
a) Rubber sheet SBR; b) SBR+M ; c) SBR+M+SBR; d) SBR+M+M+SBR; e) EVA rubber

Table 2. Resonance frequencies, quality factor Q, damping ratio δ (%) and calculated dynamic stiffness

Ho	Specimens	Thickness, mm	Resonance Frequency, Hz	f1,Hz	f2,Hz	Quality factor	Damping, %	Dynamic stiffness, MN/m2
1	SBR	3	286.12	244.6	309.1	4,4	11,3	645,7
2	SBR+M	19	66.17	56.64	71.53	4,4	11,3	34,5
3	SBR+M+SBR	22	65.94	50.3	77.15	2,46	20,4	34,3
4	SBR+M+M+SBR	28	39.96	35.16	43.70	4,67	10,69	12,6
5	EVA	26	27.33	20.508	34.18	2,00	25,00	5,9

The value of the dynamic stiffness of the recycled materials SBR+M and SBR+M+SBR is about 34.5 MN/m^2. Increasing the thickness of the resilient layer to 38 mm leads to a decrease in the value of the dynamic stiffness and it is 12.5 MN/m^2. For comparison, the result of the EVA tire, where the dynamic stiffness is approximately 6 MN/m^2, is also given. However, insulation layers with a high elasticity coefficient, under load, deteriorate the acoustic properties. Harder insulating layers will retain their insulating properties longer (Belli et al.,2003).

In Baron et al. (2004) the dynamic stiffness is given for various polymers used as elastic materials, e.g. synthetic polystyrene or treated rubber material mixed with elastomeric elements and their values are lower than 30 MN/m^3. The lower the dynamic stiffness, the better is the impact noise isolation. According to Segura et al. (2015) the dynamic stiffness values of some commercial resilient layers for floor applications are below 20 MN/m^3. According to Belli et al. (2003), Schiavi et al. (2007), Schiavi et al. (2015) once the resonant frequency and the damping ratio are known, it is possible to estimate the impact sound reduction and predict the behavior of the floating floor insulation layers (Belli, et al.,2003).

Conclusion

The paper presents a study of the properties of recycled rubber sheets and panels. These rubber products have low sound absorption and are not suitable as sound absorbing materials. In addition, the sound insulation properties against airborne and impact noise were investigated using small acoustic chambers. The average values of the sound insulation coefficient are about 36-38 dB for both the rubber crumbs plate and the SBR+M+SBR panel. These recycled materials can be used for sound insulation of walls, floors and ceilings, etc. and have potential for vibration insulation. Some results were also obtained for the dynamic stiffness. As the thickness of the insulating rubber layers increases, the stiffness decreases. Knowing this characteristic enables an indirect assessment of impact noise reduction in the application of recycled rubber products as underlays for floating floors.

Recommendations

The presented research can provide new knowledge to students and engineers about evaluation of the acoustic properties of recycled rubber products.

Scientific Ethics Declaration

The author declares that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

Acknowledgements or Notes

This article was presented as a poster presentation at the International Conference on Technology, Engineering and Science (www.icontes.net) held in Antalya/Turkey on November 14-17, 2024.

References

Abou-zeid, M., Elsaeed, A., & Ghaly, A. (2019). A proposed use of sound insulation systems. *CSCE Annual Conference, Canadian Society for Civil Engineering*, 1-7.

Asdrubali, F., D'Alessandro, F., & Schiavoni, S. (2008). Sound absorbing properties of materials made of rubber crumbs. *Journal of the Acoustical Society of America, 123*(5), 3037.

Balmori, J. A., Casado-Sanz, M., Machimbarrena, M., Quirós-Alpera, S., Mostaza, R., & Acuña, L. (2023). The use of waste tyre rubber recycled products in lightweight timber frame systems as acoustic ınsulation: A comparative analysis of acoustic performance. *Buildings, 14*(1), 35.

Baron, N., Bonfiglio, P., & Fausti, P. (2004). Dynamic stiffness of materials used for reduction in impact noise: Comparison between different in measurement techniques. *Acoustica, Paper ID*, *66*, 1-8.

Belli, A. P., Russo, F., & Schiavi, A. (2003, May). Measurement of dynamic stiffness to estimate the reduction in impact sound pressure level. In *Proceedings of the 5th European Conference on Noise Control* ,19-21.

Benkreira, H., Khan, A., & Horoshenkov, K.V. (2011). Sustainable acoustic and thermal insulation materials from elastomeric waste residues. *Chemical Engineering Science*, *66*, 4157–4171.

Branco, F.G., Godinho, L., Pereira, A., & Masgalos, R. (2010). Analysis of impact sound reduction by floor coverings using a small-sized acoustic chamber, *Proceedings of Conference Internoise, 2010*(8),2805-2815.

Carbajo, J., Poveda, P., Segovia, E., Prieto, A., Río-Martín, L., Pastor, J.D., & Ramis, J. (2024). An alternative approach to determine the dynamic stiffness of resilient materials under low prestatic load. *Applied Sciences*. *14* (11), 4925.

ENISO, I. (2001). *10534-1, determination of sound absorption coefficient and ımpedance in ımpedance tubes part 1: Method using standing wave ratio*. British Standards Institution.

Fahy, F. (2000). *Foundations of engineering acoustics* (1st ed.). Elsevier.

Godinho, L., Masgalos, R., Pereira, A., & Branco, F. G. (2010). On the use of a small-sized acoustic chamber for the analysis of impact sound reduction by floor coverings. *Noise Control Engineering Journal*, *58*(6), 658-668.

Isaac, C.W., Pawelczyk, M., & Wrona, S. (2020). Comparative study of sound transmission losses of sandwich composite double panel walls. *Applied Sciences, 10* (4), 1543.

Kim, T. M., & Kim, J. T. (2011). Comparison study of sound transmission loss in high speed train, *IJR International Journal of Railway*, *4* (1),19-27.

Kumar, D., Alam, M., Zou, P.X.W., Sanjayan, J.G., & Memon, R.A.(2020). Comparative analysis of building insulation material properties and performance. *Renewable and Sustainable Energy Reviews*, *131*, 110038.

Martin, F. (2014). *Recycling and re-use of waste rubber.* Shawbury, UK: Smithers.

Medina, N.F., Garcia, R., Hajirasouliha, I., Pilakoutas, K., Guadagnini, M., & Raffoul, S. (2018). Composites with recycled rubber aggregates. Properties and opportunities in construction. *Construction and Building Materials, 88*(1–2), 884-897.

Nuzaimah, M., Sapuan, S.M., Nadlene, R., & Jawaid, M. (2018). Recycling of waste rubber as fillers: A review. *IOP Conference Series: Materials Science and Engineering, 368*, 012016.

Pleban, D., & Mikulski , W.(2018). Methods of testing of sound insulation properties of barriers intended for high frequency noise and ultrasonic noise protection. *Journal of mechanical engineering – Strojnícky časopis*, *68*(4), 55 – 64.

Reddi, Chi, & Naidu B. (2020). Construction of small twin reverberation chamber for measurement of sound transmission loss, *Proceedings of 49th International Congress and Exposition on Noise Control Engineering "Internoise 2020",* 1-12.

Rushforth, I.M. , Horoshenkov, K.V., Miraftab, M., & Swift, M.J. (2005). Impact sound insulation and viscoelastic properties of underlay manufactured from recycled carpet waste. *Applied Acoustics, 66*,731–749.

Schiavi, A., Pavoni -Belli A., Corallo, M., & Russo, F. (2007). Acoustical performance characterization of resilient materials used under floating floors in dwellings. *Acta Acustica United with Acustica, 93*(3), 477-485.

Schiavi, A., Prato, A., Barbaresi, L., & Semprini, G. (2015). The effect of damping in resilient materials used in floating floors on impact sound insulation. *Atti del Convegno ICSV22, Firenze*, 12-16.

Schiavoni, S., D'Alessandro, F., Bianchi, F., & Asdrubali, F. (2016). Insulation materials for the building sector. A review and comparative analysis. *Renewable and Sustainable Energy Reviews*, *62,* 988–1011.

Segura J. G., Julia, E., & Gadea, J. M. (2015). Impact acoustic isolation of ethylene vinyl acetate panels. *Annals of the Oradea Universit , Fascicle of Management and Technological Engineering*, *1*, 245-248.

Valentini, F., & Pegoretti, A. (2022). End-of-life options of tyres. *Advanced Industrial and Engineering Polymer Research, 5*, 203-213.

Vilniškis, T., & Januševicius T. (2024). Sound insulation properties of sound-reduction louvers with innovative devulcanized rubber. *Archives of Acoustics*, *49* (3), 359–368.

Wen, Z. H., Wang, D. W., & Ma, L. (2021). Sound transmission loss of sandwich panel with closed octahedral core. *Journal of Sandwich Structures & Materials*, *23*(1), 174-193.

Zebra-AD. (n.d.). *Products.* Retireved from https://www.zebra-bg.com/en/products.

Author Information

Yonka Ivanova
Sofia University "St. Kliment Ohridski", Faculty of Physics, Bulgaria
Institute of Mechanics at Bulgarian Academy of Sciences, Sofia, 1113, Acad. G. Bontchev Str.,bl.4, Bulgaria
Contact e-mail: *yonivan@phys.uni-sofia*.

Todor Partalin
Sofia University "St. Kliment Ohridski",
Faculty of Mathematics and Informatics, 1164 Sofia, 5 James Bourchier Blvd. Sofia, Bulgaria.

To cite this article:

Ivanova Y., & Partalin, T. (2024). Experimental study of acoustical properties of recycled rubber panels. *The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 32*, 379-388.