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Properties of Sound Panels Made from Recycled Footwear Treads

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Natural resources have been decreasing with the large expansion of the world's population. In order to supply raw material for production, new recycling approaches should be developed for waste materials. Worn shoes is one of the most common waste products that can be recycled for this purpose. According to the record, shoes are very complex products, as they can be produced from forty different materials, like leather, rubber, polymers etc. Especially the bottom layers of the shoes are made from sound absorbing materials like polyurethane, thermoplastic rubber and PVC. Because today's technology is not able to separate these materials from each other during recycling, they should be used in a homogenised state. Thus these parts were shredded into small granules and mixed. PU binder and hot press were used to obtain samples for tests. In this paper sound absorption, sound isolation, vibration isolation and thermal insulation properties of the tread mixture are investigated. In addition to that, the mechanical properties of the material were also investigated by measuring the compression strength of the material.

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1. Introduction

Increase in the number of people, who follow fast fashion trends, and the mass production have resulted in the increase in consumption of many industrial goods. This product range also involves footwear sector [1]. According to World Footwear, footwear production and consumption has been doubled every 20 years [2]. However, fast consumption causes enormous number of waste, increase in raw material cost due to lack of raw material and also environmental pollution. During the textile product recycling, main aim is not to harm environment and people [3]. The waste management strategies for footwear products can be listed as disposal, reuse and recycling [1]. Although reuse strategy is more sustainable than disposal, shoes are not always in a good condition for charity. When all of the waste management strategies are considered, the most suitable option is to recycle [1]. Today, unfortunately, only 5% of waste shoes are recycled according to data from World Footwear [4]. According to Lee & Rahimifard, the main reason of low recycling rate is the complex body structure of a shoe, which contains rubber, polymers, metal, leather and textiles [1].

Noise pollution is another problem faced by people in 21st century. To prevent sound pollution, sound absorbing materials are preferred to use. Arenas and Crocker argued that the materials that have better sound absorption are the ones with porous structure, which means shredded materials gathered together by a binder. In addition to that, the granulated structure provides different sizes of gaps between the granules, so that material has better sound absorption properties. When granulated structures are deeply considered, most of them are made of the recycled rubber and foam [5–7].

A basic sports shoe is made of many parts with wide variety of materials, however the most important part is the sole, which is usually made of rubber, PVC and PU, which makes it easier to be shred and used in granulated state. Mixture of shredded granules with binder provides granulated structure. Acording to Berkalp et al., performance of sound absorbing panel depends on the amount of binder which is used to bind the materials, as well as the amount of granule mixture [8].

Vibration isolation can be defined as the transformation of mechanical energy into heat during vibration. Elastic materials can turn energy into heat very efficiently, so they are used as vibration isolators. Skripkiūnas investigated the effect of recycled rubber on vibration in a mixture and concluded that increasing the amount of recycled rubber increases the vibration isolation property of the material. Author also proves that these panels can be used as sound absorbing panels [9].

The aim of this project is to reduce fuel oil consumption by recycling old shoes and reusing them instead of using synthetic sound absorbing materials. For this purpose, the soles of waste shoes are used in granule form and based on their acoustic, thermal and damping properties, the alternative usage areas are investigated. The aramid, glass and carbon fiber are added to improve certain properties of the composite materials [10, 11]. Thus, the characteristics of different compositions were investigated by adding shredded jute fiber and shredded glass fiber in different ratios.

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2. Experiment

2.1. Materials

Granulated waste shoe soles were used as the main material in this project. Shoes with different types of soles were collected. First, sole of each shoe was separated by manual sorting. Manual sorting was done very carefully, to remove any leather or metal residues on the sole of the shoe. All soles were granulated by using a shredder with 10 mm mesh diameter and, at the end, a homogeneous mixture of rubber granules, with granule diameter of around 8–10 mm, were obtained.

Prepared granules were mixed with polyurethane binder, to obtain homogeneous mixture. Polyurethane rubber binder is preferred to gain rigid and flexible structure. During sample preparation, polyurethane rubber binder, A391, supplied by DUAYEN, was used. Cast iron mould with the size of $110 \times 110 \times 20$ mm^3 was used to prepare samples. After moulding, pressure of 3 bar was applied to homogeneous mixture by using a hydraulics press. Thus mixture was stabilized under pressure. Then, for curing, it was placed into reheating furnace at 150 °C for 15 minutes. In the previous studies, it is claimed that the amount of binder used for samples affects directly the acoustic properties of the samples. Due to that reason, in this study, the amount of binder is kept constant for all samples [12].

In addition, granules were mixed with 8–10 mm long glass fiber and jute fiber, to investigate the effect of different material compositions. Sample compositions are shown in Table I. Since the effect of glass and jute fiber was planed to be investigated, the amount of binder was the same in all samples. Amounts of glass fiber and jute fiber were calculated in units of mass percent. Sample, which included only sole granules is called reference (R). Jute samples are named based on the amount of jute in the mixture, for 10% jute, it is J10, and for 20% jute, it is J20. Samples with glass fibers are named using the same principle. For each sample, three specimens were prepared for each experiment.

TABLE I

Sample compositions.

Sample name	Amount of rubber [g]	Amount of binder [g]	Amount of jute fiber [g]	Amount of glass fiber [g]
R	135	15	–	–
J10	120	15	15	–
J20	105	15	30	–
G10	120	15	–	15
G20	105	15	–	30

2.2. Acoustics and sound absorption test

Sound absorption test was performed in order to determine sound absorption. It was carried out according to ISO 10534-2 [13]: Acoustics – Determination of sound absorption coefficient and impedance in impedance tubes. Specimen dimensions differ based on the frequencies used during the experiment. For low frequencies, samples with dimensions of $\varnothing 100 \times 20$ mm were used, on the other hand, for high frequencies, the dimensions were $\varnothing 29 \times 20$ mm. The specimens were tested by using Brüel&Kjaer TYPE 4206-T transmission loss and impedance tube kit. This experiment setup has the measurement range of 50 Hz–6.4 kHz. The experiment is carried out at ambient temperature of 25 °C.

Equations (1) and (2) were used to determine the transmission loss of the material.

$$H_{\mathrm{c}} = \left(H'_{12} H''_{21}\right)^{1/2}, \tag{1}$$

$$H_{12} = |H_{12}| \, \mathrm{e}^{j\phi} = \frac{H_{12}}{H_{\mathrm{c}}}, \tag{2}$$

where H'_{12} is normal microphone direction, H''_{12} is reverse microphone direction, H_{c} is calibration factor, H_{12} is transmission function. In the situation of reverse microphone direction, the microphone locations were changed with each other.

The sound absorption coefficient is determined using Eqs. (3) and (4).

$$r = \frac{H_{12} - H_{\mathrm{I}}}{H_{\mathrm{R}} - H_{12}}, \tag{3}$$

$$\alpha = 1 - |r|^2, \tag{4}$$

where r is reflection factor, α is sound absorption coefficient. The $\varnothing 100$ mm specimen was tested in 50 Hz–1.6 kHz frequency range. The $\varnothing 29$ mm specimen was tested in 50 Hz–6.4 kHz frequency range.

2.3. Modal analysis

Modal testing is a very basic method to determine the mechanical properties of a material, like Young modulus and vibration loss factor via FRF function of the system. ASTM E 756 [14] standard is used to determine the vibration loss factor of the specimens.

2.4. Thermal conductivity

Thermal conductivity constant is calculated to investigate both, the thermal conductivity of the sample, and the effect of the other materials, which were added to the composition. For this purpose, an experimental setup which has an electric heater from middle surface and cooler from top and bottom surfaces is used. System is cooled by using an aluminum billet, 100 mm in diameter and with thickness of 100 mm, which has a cooling solution inside. A copper plate is placed on aluminum billet and on the top of the copper plate the sample is placed. Then heater is placed on the sample. Finally, another pair of aluminum billet and copper plate is located on the top of the sample.

The experimental setup is fully covered by fiberglass, used as an insulating material. Temperature is followed using K-type thermometers located on aluminum billets, copper plates and heater. Data is collected using Keithley 2700 data acquisition system.

2.5. Compression test

Due to the intended future usage and discontinuous nature of the samples, compression test were conducted on the specimens. Test samples were prepared using dimensions of $\varnothing 29 \times 20$ mm. The compression test was carried out with Shimadzu, AG-IS 50 kN universal tensile tester.

3. Results and discussion

3.1. Acoustic properties

Acoustic properties of the composite material were measured for both high and low frequencies, as shown Fig. 1. When sound absorption properties of samples are observed, it is seen that all compositions of samples are effective between 1500–2500 Hz. Both, the R sample and the glass fiber containing samples present the highest absorption capabilities in this range. They have shown the best sound absorption value (100%) at 2164 Hz. However, there was a sudden drop in R sample above the position of maximum value, from 100% to 25% within 1000 Hz range.

Both jute added samples have been more effective in the lower frequency range, which is a more critical range for most of the applications. Besides, J20 has shown almost no change between 1000 to 6000 Hz. In certain application, early sound absorption increase is more important. According to current study, G20 sample had the best response in first 500 Hz range, among all tested samples.

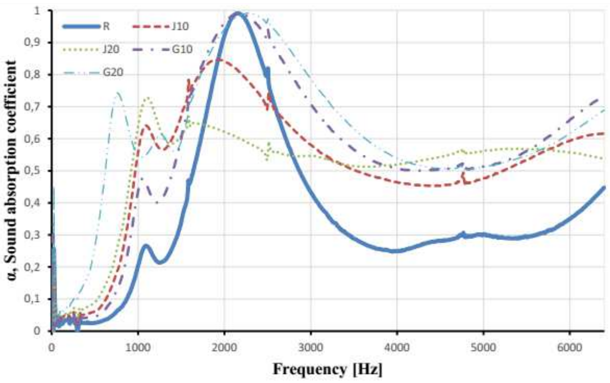

Fig. 1. Sound absorption coefficient of the specimens.

Transmission loss measurements were also conducted during the sound absorption tests. All transmission loss test results have the similar fluctuating trend in entire test range. This may be caused by the large particle size of the composites. Similar results have been obtained in transmission loss tests with sound absorption. Reference sample R and glass fiber added samples (G10 and G20) have a similar loss behaviour. They have shown highest transmission loss around 2000 Hz range. Then they have shown a steady trend around range of 5 to 10 dB. Jute added samples have almost two times higher transmission loss than those of other samples. Higher jute content has also caused a higher transmission loss value. J20 sample has reached 20 dB loss at 6000 Hz.

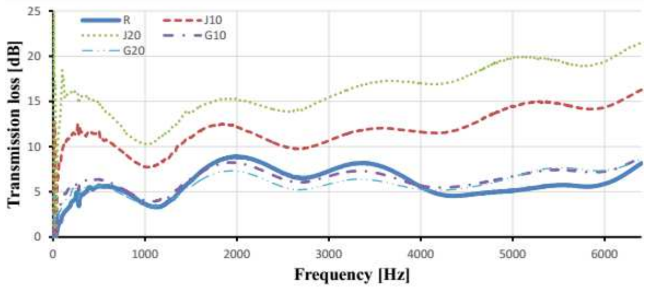

Fig. 2. Variation of transmission loss with frequency, for all tested samples.

3.2. Modal analysis

Modal analysis results for loss factor calculation are given in Fig. 3. First response peak around 10 Hz was omitted and the 2nd, 3rd and 4th modes were analysed. According to the analysis results, the most useful data were calculated between the frequency range of 100 to 550 Hz.

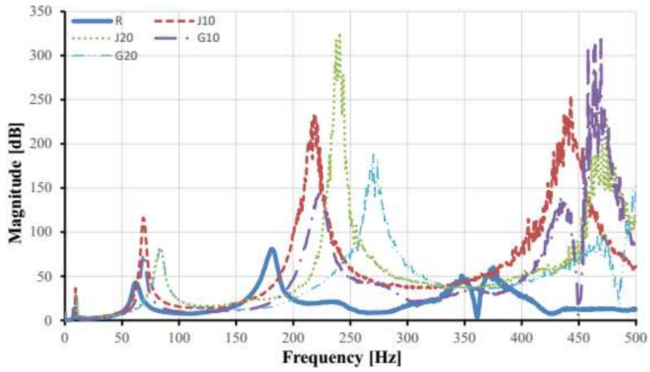

Fig. 3. FRF change of samples in modal analysis.

Results of calculated loss factor can be seen in Fig. 4. The loss factor is a parameter which shows the relative material damping capabilities. According to the test results, damping abilities of glass fiber and jute added test samples were more consistent than that of R sample. Both mixed samples show increasing capabilities from 100 to 500 Hz. The highest loss factor percentage has been calculated for low glass fiber containing sample. R sample demonstrated a different trend, its loss factor increases up to 2.5% between 100 to 300 Hz, than it slightly decreases to the end of analysis range. This analysis suggested that addition of material into recycled structure helps to increase damping ability.

3.3. Thermal conductivity

Results of measurements of the coefficient of thermal conductivity for all samples are tabulated in Table II. According to the test results, the R sample has the highest thermal conductivity value, however other values were

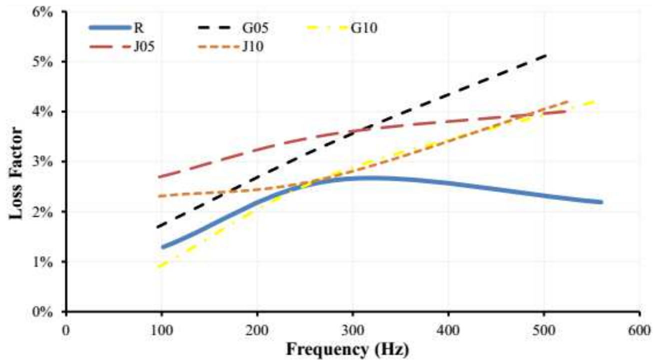

Fig. 4. Loss factor.

not much different than from that of R sample. All changes of the coefficient of thermal conductivity were in the 10% range.

When amount of jute was increased in the composite structure, it improved the thermal isolation property of the material by about 2.5%. The higher glass fiber content had also increased the thermal resistivity of the material by almost 7.5%. This also proves the thermal resistance or isolation properties of glass fiber, which is used in buildings as a thermal barrier. This result was obtained due to the cellular structure of composite, which is provided by granules of the samples.

TABLE II

The coefficient of thermal conductivity of tested samples.

Specimen	R	J10	J20	G10	G20
The coefficient of thermal conductivity [W/mK]	0.358	0.357	0.349	0.336	0.331

3.4. Mechanical properties

The results of R sample compression test are given in the Fig. 5 as an example. Surprisingly, addition of jute has increased the strength significantly, from 0.8 MPa to 3.25 MPa. However there was no effect of glass fiber addition. The 10% increase of jute content has caused almost 25% increase in compression strength.

4. Conclusions

In this study, waste shoe sole granules were tested as an alternative sound and energy absorbing material for potential applications. Test samples were filled with jute and glass fiber in different percentages. Acoustic and sound absorbing test, modal analysis, thermal conductivity measurement test and compression test were conducted on these test samples. According to the test results;

1. Both, the R sample and glass fiber added samples presented the highest absorption capabilities in the 1500–2500 Hz frequency range.

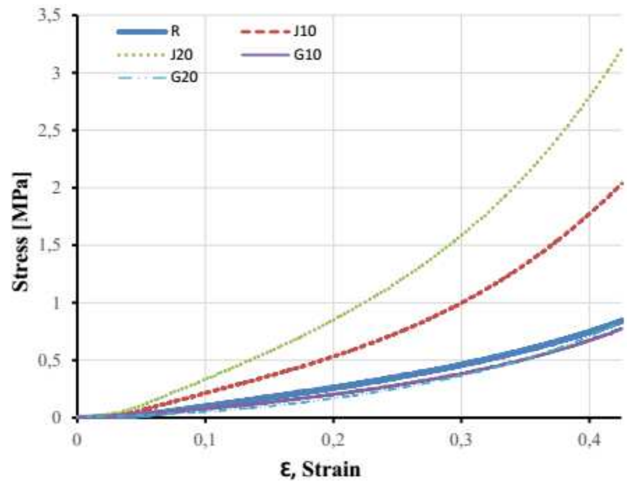

Fig. 5. Stress-strain plot.

2. J20 sample has shown almost no change of sound absorption value between 1000 and 6000 Hz.
3. G20 sample had the best response in the first 500 Hz range of sound absorption test.
4. Jute added samples had almost two times higher transmission loss than those of other samples.
5. The highest percentage of loss factor has been calculated for low glass fiber content sample.
6. The result of loss factor measurements suggests that addition of the fiber material to recycled structure helps to increase damping ability.
7. The increasing addition of glass fiber also increases thermal resistivity of the material by almost 7.5%.
8. Addition of 20% of jute fiber increases compression strength of the composite from 0.8 MPa to 3.25 MPa.

References

[1] M.J. Lee, S. Rahimifard, *Resourc. Conserv. Recycl.* **69**, 90 (2012).

[2] T. Staikos, S. Rahimifard, *End-of-life management considerations in the footwear industry*, 2007.

[3] F. Akarslan, H. Demiralay, *Acta Phys. Pol. A* **128**, B-407 (2015).

[4] World Footwear, *The future of polyurethane soling, world footwear*, MA: Shoe Trades, Cambridge 2005, p. 18.

[5] J.P. Arenas, M.J. Crocker, *Sound vibrat.* **44**, 12 (2010).

[6] H.S. Yang, D.J. Kim, H.J. Kim, *Bioresource Technol.* **86**, 117 (2003).

[7] Y. Liu, *J. Sound Vibration* **339**, 376 (2015).

[8] Ö.B. Berkalp, İ. Yalçın, M. Küçükali, B.U. Nergis, C. Candan, M. Bakkal, in: *Int. Conf. Advances in Fuctional Textiles*, Manchester 2013.

[9] G. Skripkiünas, A. Grinys, K. Miskinis, *Mater. Sci. (MEDZIAGOTYRA)* **15**, 266 (2009).

[10] S. Eksi, K. Genel, *Acta Phys. Pol. A* **128**, B-59 (2015).

[11] N. Ozsoy, M. Ozsoy, A. Mimaroglu, *Acta Phys. Pol. A* **130**, 297 (2016).

[12] M.J. Swift, P. Brisb, K.V. Horoshenkova, *Appl. Acoustics* **57**, 203 (1999).

[13] TS EN ISO 10534-2: 2003-04.

[14] ASTM E756-05: 2010.