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ORIGINAL PAPER

Green Composite Sound Absorber Production from Orange Peel Waste for Efficient Sound Insulation

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Abstract

Introduction Porous materials have poor acoustic absorption coefficient in the low-frequency range. Adding natural waste materials (e.g., cotton) with good sound absorption values at low frequencies to resins, such as acrylic and polypropylene, improves acoustic performance at low frequencies. There is no study on the production of sound insulation material using orange peel and resin. The study will contribute to the literature with green composite sound absorbing materials produced with the help of green technology using commercial water-based acrylic resin and orange peel.

Objectives It is aimed to design and develop cost-effective green composite sound insulation materials produced using orange peels and commercial acrylic resins as agricultural waste.

Methods First, the orange peels were dried and ground at room condition. Second, green composite sound insulation materials were produced using commercial acrylic resins. Finally, the sound insulation performances of the produced materials were determined and characterization tests were applied to the materials.

Results The highest sound absorption performance of the sound insulation materials produced from orange peel for 10 Hz, 100 Hz, and 1 kHz, respectively, was observed as 26%, 17.1%, and 37.5% in OP-20. OP-20 exhibited similar properties with commercial sound insulation materials.

Conclusion The developed porous sound insulation material exhibited similar performance to commercial sound insulation materials at low frequencies. The developed green composite sound absorbers were produced very cheaply, because they were produced using orange peel and commercial acrylic resins, which are in the category of free waste. As a result, farmers living in rural areas will use their agricultural wastes for insulation purposes instead of burning them, creating employment in a new area and saving a significant amount of energy. The developed green composite insulation material is a candidate for commercialization in the future.

Keywords Orange peel waste · Sound insulation · Agricultural waste · Sustainability · Circular economy

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Introduction

Noise pollution due to urbanization and modernization arises from the developments that took place due to the inter-sectoral revolution to facilitate human life in the twentieth and twenty-first centuries [1, 2]. It is considered as one of the worst and widespread environmental problems, today, that are getting more complex and serious and worsening day by day [3, 4]. It is of great importance to control the noise coming from the living environment, as people around the world face serious health risks such as restlessness, anxiety disorder, tinnitus, sleep disorder and even chemical heart disease due to noise pollution with the development of transportation and rapid urbanization [5].

Since comfort in people's homes is of primary importance, there is an increasing need for the use of inner finishing materials that help bring the interior sound field to a comfortable level. It is also very important to constitute an acoustically comfortable interior space, especially since low noise plays a crucial role in employee productivity [6]. To reduce the noise produced by various sources in the industry, it is widely preferred, because the most effective method is to use sound absorbing and insulation materials [3, 5]. Porous and fibrous materials frequently used in production environments, buildings and vehicles are glass wool, mineral fibers and foams [3]. Available commercial sound isolation materials are separated into resonance and porous sound isolation materials.

Compared with porous sound absorbing materials and other sound absorbing materials, they are more advantageous due to their outstanding properties, such as large absorption frequency range, low cost, weight reduction and easy molding. Widespreadly used porous sound absorbing materials can be ordinated as foam and fibrous sound absorbing materials. Sound isolation foams consist of interconnected cellular structures, while fibrous sound isolation materials contain multiple channels between structured fibers, which may be continuous fibres or batch fibers. Sound isolation foams can be ordinated into three groups as organic, inorganic and hybrid foams depending to the chemical mixture of the materials [5]. At the same time, conventional acoustic foams are formed homogeneous clear holes difficult it to grow of thin foam layers [1].

Some of the sound absorbing materials are made from agricultural wastes called "green materials" [3]. Non-woven fibers such as polyester and cotton blends are useful for sound isolation at high frequencies and acrylic and polypropylene should be added to these fibers to improve acoustic productivity at lower frequencies. The proportion of fiber blend largely affects the sound absorption coefficient and air transparency. Increasing the fiber percentage in the polyester–cotton–two-component blend reduces the sound absorption rate. Similarly, multilayer fiber nonwoven fibers provide more resistor to airflow than one layer fibers. Reducing the fiber size also increases the sound absorption properties. Palm fiber (123 µm) has a higher sound absorption coefficient than coconut fiber (252 µm). Sound isolation panels generated from agricultural and industrial banana fiber waste are very beneficial for checking rumble pollution [1].

Binder and adhesives (usually made of biodegradable materials) such as polyvinyl alcohol (PVA), latex, corn starch, glue, white cement, for the production of sound isolation materials are specifically used to improve the level of bonding between natural fibers in prepared samples. Biodegradable binders such as PVA showed fair interaction with natural fibers, resulting in satisfactory composite properties and acceptable performance [7]. The effect of the chemical binder on sound absorption depends on the pore formation during application and the type of binder [8].

Different techniques are used to compare the acoustic productivity of porous and fibrous materials. One of the most widely used methods is to characterize materials via a steady cadence tube (impedance tube system) to determine the sound absorption coefficient in normal event [9]. The World Health Organization (WHO) has stated that daily spaces should have enough insulation to allow a Sound Pressure Level (SBS) of no more than 30 dB–40 dB [10]. Although the natural hearable frequency ranges from 20 Hz to 20 kHz, this range for humans should be 20 Hz–120 Hz [7].

One of the most important solutions to reduce noise pollution is to increase the sound absorption efficiency in houses and buildings by optimizing the pore structure of building materials as well as increasing the damping capacity [4]. These materials are especially preferred in areas such as construction and transportation due to their remarkable advantages [3, 5]. The construction industry has turned to the use of products that can reduce energy consumption, improve indoor quality and reduce environmental impact, despite their increasing costs. Moreover, it is experiencing increasing pressure to use materials based on environmentally friendly and sustainable products, especially natural and bio-based products.

At the World Economic Forum Annual Meeting in 2022, it was decided to implement the Circular Economy Model in the construction sector and cities [11]. In this context, bio-based materials derived from agricultural byproducts are an interesting alternative to those derived from fossil carbon [12]. Vegetable fibers used in acoustic absorption offer several advantages over synthetic conventional fibers, such as lower production cost, lower density and biodegradability. Therefore, research for renewable natural materials has become popular and has been a turning point for cleaner production. In addition, recent research has revealed that vegetable fibers can exhibit mechanical properties similar to fiberglass and other composite materials [13]. The use of biomass-based building materials has increased significantly, as reducing the toxicity of building materials can be an important milestone towards the eco-efficiency of the construction industry [12].

Most of the agricultural waste is incinerated on farms, posing a threat to the environment. There has been a great interest in increasing the use of these wastes in different areas instead of burning them. The use of agricultural wastes as sound absorbing materials offers a solution to both noise and environmental pollution [3]. The use of these wastes in the production of sound absorbing materials will contribute both to climate change by reducing air pollution and to sustainability and circular economy, since materials will be produced from wastes.

According to the Food and Agriculture organization (2019), approximately 70 metric tons of oranges are produced worldwide [14]. As a result of the increasing consumption and demand for orange processing, the amount of orange peel waste as agricultural waste is expected to increase [15]. Orange peel with a pH range of 2.9–4.0 contains insoluble polysaccharides (pectin (42.5% dry weight), cellulose (9.21% dry weight) and hemicellulose (10.5 dry weight), soluble carbohydrates (such as glucose, sucrose and fructose), high fiber content and low protein [16, 17]. Research has been carried out on the water absorption abilities of different composites produced from orange peel, which is a biodegradable and environmentally friendly supplement [16].

Orange peels are promising bio-additive candidates for polymer composite production due to their wide availability, low cost, biocompatibility and biodegradability, which can offer great opportunities to develop value-added and environmentally friendly structural composites from waste [18]. Traditionally, most of the orange peel waste is disposed of by incineration or recycled as animal feed or composting. While recycling initiatives are in place, they are of low value [15]. Orange peel wastes are used for acoustic purposes as well as their original use in composite technology. Composites produced by treating orange peels with a binder have higher strength due to the high compatibility of the matrix and reinforcement interface [16].

Maderuelo-Sanz et al. produced suspended ceiling tiles using rice husk, vine pruning residues, cork (white cork, virgin cork and expanded cork), prickly pear raw materials and water-based acrylic resin. Such bio-based panels can be used as an alternative to conventional materials used for noise control applications such as glass wool, foam or rock wool in commercial areas such as indoor entertainment areas [19].

In the study, it was aimed to reveal the sound insulation potential of green composite sound insulation materials produced using orange peels, which are agricultural waste, and acrylic resins as binders. The sound absorption performances of the produced sound absorbing materials were realized with the help of impedance tube at 10 Hz, 100 Hz and 1 kHz frequencies. The produced composite sound insulation materials showed similar sound insulation potential properties to commercial sound insulation materials. There is no study in which sound insulation material is produced using orange peels and resin. The study will contribute to the literature with green composite sound absorbing materials produced with the help of green technology using commercial water-based acrylic resin and orange peels.

Materials and Methods

Materials

The orange peels were collected before they were thrown away during the winter. Styrene acrylic copolymer (ASA) and Vinyl acrylic copolymer (AVA) resins were obtained from ASAL Boya Kimya Sanayi Tic. Ltd. Sti. (Fig. 1).

Zirconium (IV) oxychloride octahydrate ($ZrOCl_2.8H_2O$), which is used to provide strength to the sound insulation material, was purchased from Merck and Sodium Alginate (SA) was produced by Smart Kimya Tic. and San. Ltd. Sti. was purchased from the company. Commercial sound insulation materials (Auto Sound Insulation Material [ASIM (Fig. 2a)] (3 mm thickness), Decibel Acoustic Sponge Fireproof Pyramid Sponge [DASFPS (Fig. 2b)], Sound

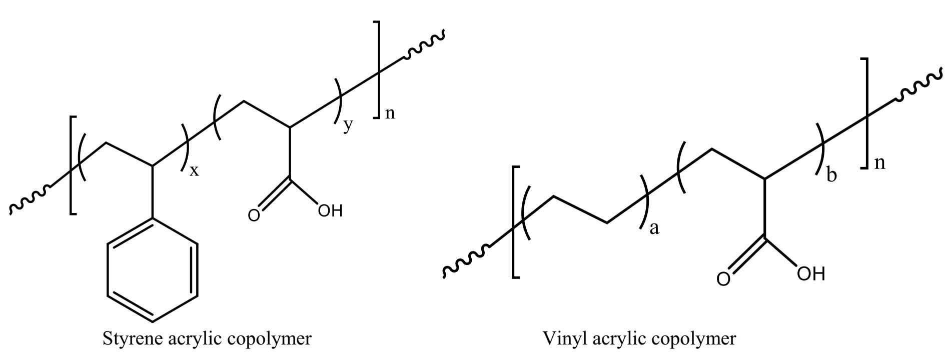


Fig. 1 Structural formula of acrylic resins used [20]

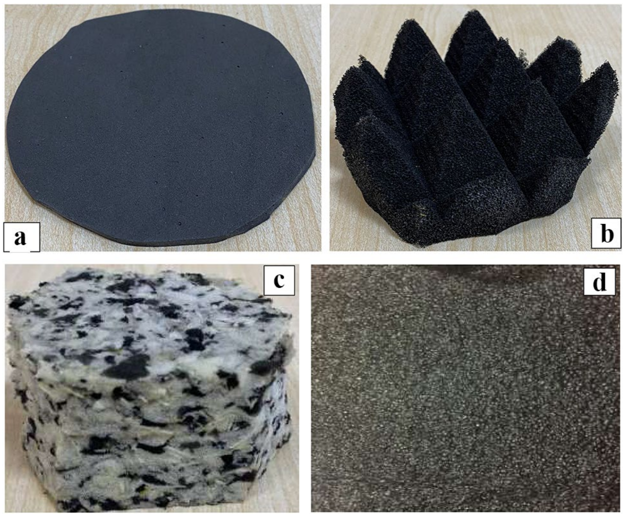


Fig. 2 Commercial sound insulation materials (**a** = Auto Sound Insulation Material (ASIM) (3 mm thickness), **b** = Decibel Acoustic Sponge Fireproof Pyramid Sponge (DASFPS), **c** = Sound Insulation Sponge Bondex (SISB) (50 mm thickness), **d** = Rubber Floor Sponge(RFS)

Insulation Sponge Bondex [SISB(Fig. 2c)] (50 mm thickness), Rubber Floor Sponge [RFS (Fig. 2d)] determined by researching customer comments of internet sales sites were obtained from n11.com site.

Methods

Green Composite Sound Insulation Material (GCSIM) Production

In order not to lose the volatile components in its structure, the orange peels were dried in an oven at 50 °C for 1 night (Fig. 3a). The dried peels were ground using a laboratory blender (Fig. 3b).

SENAY process [20] was modified and mixed with AVA and ASA, followed by adding GOPs, 2.5% SA and $ZrOCl_2.8H_2O$, respectively. The mixture was shaped by pouring into a mold and cured at room conditions for 3 days to produce sound absorbing materials (Fig. 4). The sound insulation performances of the materials produced with the help of impedance tube were determined. To determine the sound insulation performances, 10 Hz, 100 Hz and 1 kHz frequencies were chosen, since > 100 dB sound pressure is provided. According to the highest sound insulation performance of the produced materials, first the most suitable GOP amount and then the most suitable AVA and ASA amounts were determined. GCSIMs were produced according to the ratios given in Table 1. Each experiment was repeated three times and the results were averaged.

Characterization

At one end of the impedance tube is a sound source (speaker) that generates planar and random sound waves. The material is placed in the middle of the tube. During propagation of plane waves, some of the waves are trapped in the sample. These waves are separated as parts that are reflected to the tube by the sound source, absorbed by the material, and passed from the material to the receiving tube. Some of the plane waves passing through the material pass to the end of the receiving tube. Here, some of the waves are reflected and some exit the tube. For this reason, the measurement is carried out with two different finishing methods [21].

When an acoustic wave circulating in one medium encounters the boundary of a second medium, reflected and transmitted waves are produced. Sound wave propagation is directly affected by the properties of the medium. Therefore, when a sound wave passes into a medium with a different cross section, material property, or temperature, some of the sound energy is returned to the source, thus the energy of the trailing wave is lost [22].

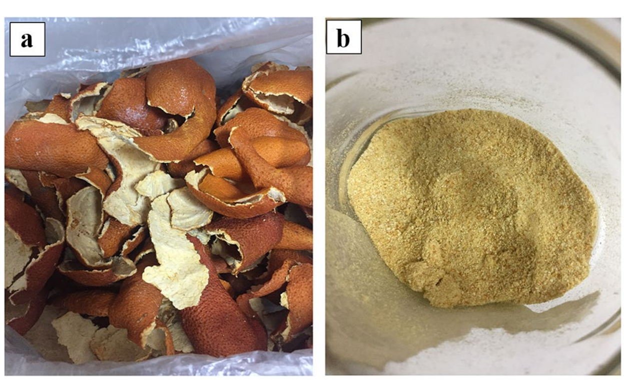


Fig. 3 Dried orange peels (**a**) and ground orange peels (GOPs)(**b**)

Fig. 4 Green composite sound insulation material (GCSIM)

Table 1 Recipes of green composite sound insulation materials

	OP-10	OP-15	OP-20	OP-30	VA-0	VA-10	VA-30	VA-40
GOP(g)	10	15	20	30	20	20	20	20
AVA (g)	20	20	20	20	0	10	30	40
ASA(g)	20	20	20	20	40	30	10	0
2.5% SA (ml)	25	25	25	25	25	25	25	25
$ZrOCl_2.8H_2O$ (g)	1	1	1	1	1	1	1	1

Measurements to determine sound transmission loss (sound insulation performance) were performed with a four-microphone impedance tube assembly according to the ASTM E2611 test method [23]. Sound absorption performance standard deviations of green composite sound insulation materials were determined as ≤ 5%. Microphones show 1/2 inch condenser microphone measuring in the range of 30–130 dB, sensitivity of ± 1.5 dB, resolution of 0.1 dB, frequency response of 31.5 Hz ~ 8 kHz.

The elemental content of GOP was determined with the help of LECO CHNS 628. Ash, moisture and volatile matter analyzes were carried out according to ASTM (D3174-12, D5460-02, D3175-11) standards. Surface morphology (Surface morphology (SEM-ZEISS Supra 40VP) brand scanning electron microscope (1.3 nm at 15 kV)) and functional structure (Perkin Elmer Spectrum 100 model FT-IR spectrometer, 400–4000 cm^{-1} wavelength) analyzes were applied to the GOP. Surface morphology (SEM-ZEISS Supra 40VP brand scanning electron microscope (1.3 nm at 15 kV)) and functional structure (Perkin Elmer Spectrum 100 model FT-IR spectrometer, 400–4000 cm^{-1} wavelength) analyzes of green composite soundproofing materials has been carried out. At the same time, tensile, mechanical strength, swelling degree and density tests were carried out. Density tests were determined by the ratio of the mass of the soundproofing material to its volume. Shrinkage ratios (volumetric shrinkage) are the ratio of the volume of the material before curing to the volume after curing. The composite material was kept in distilled water at room temperature for 24 h and the degree of swelling was determined according to the following equation [24]:

$$\text{Swelling}\,(\%) = \left[\left(M_2 - M_1\right)/M_1\right] * 100 \tag{1}$$

M_2 = Weight of GCSIM swollen in water.
M_1 = Dry weight of GCSIM.

Mechanical strengths were determined with the help of ELE CBR-Test-50. The standard deviations of the physical properties of green composite sound insulation materials are determined as ≤ 5%.

Results and Discussion

Characterization of GOP

The chemical composition of orange peel consists mainly of > 70% cellulose, > 15% lignin and > 5% hemicellulose. Cellulose is the simplest natural polymer that turns into its monomers [25]. Compounds content of orange peel are saponins, alkaloids, tannins, flavonoids, sugars, resins, terpenes and phenolic. It has not coumarins and steroids [26]. The volatility of the various compounds in orange peel is remarkable—the terpenes that match essential oils are volatile compounds that usually start phase change around 60 °C [25].

Elemental and proximate analysis results of GOP are given in Table 2. The volatile matter ratio of GOP is 82.42% and the oxygen ratio is 51.688%, which indicates that volatile compounds are present in excess in the GOP structure.

Lignin, cellulose and hemicellulose structures showed different bands in the FT-IR spectrum of orange peel [16, 27]. C–O–H or C–O–R bands of alcohols or esters were observed at 1045 cm^{-1} and the C–H peak at 2923 cm^{-1} [27]. $–CH_2–$ and $–CH_3–$ bands formed by aliphatic chains that form the basic structure of lignocellulosic materials exhibit bending vibrations of approximately 1420 cm^{-1} [27]. The C = O band observed at 1732 cm^{-1} is due to lignin [16]. Peaks from 1605 cm^{-1} to 1022 cm^{-1} are attributed to lignin containing lignocellulosic fiber. The 1275 cm^{-1} band is formed due to aromatic skeletal stretching [16] (Fig. 5).

Numerous cavities can be seen on the surface of the orange peel, usually the lumen, which is mostly found in biofiber cells. It has been confirmed that a group of natural cells, such as lignin and pectin, are bound by natural polymers containing

Table 2 Elemental and proximate analyses of GOP

C(%)	H(%)	S(%)	N(%)	O(%)*	VM (%)	M (%)	A (%)	Sbt Carbon (%)**
40.42	6.7	0	1.012	51.868	81.42	6.66	3.03	8.89

*O(%) = 100-(C + H + S + N)

**Sbt carbon = 100 – (Volatile Matter(VM) + Moustire(M) + Ash(A))

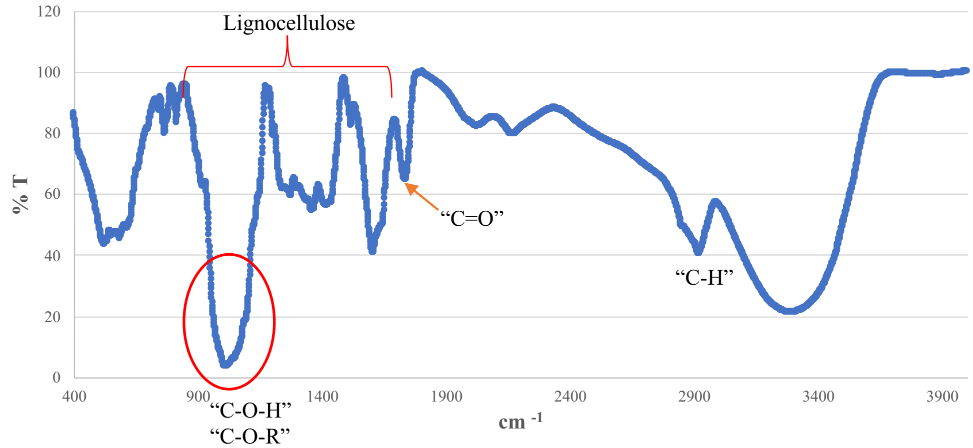
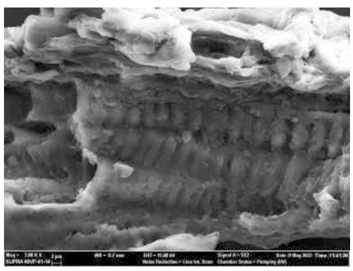


Fig. 5 Orange peel FT-IR spectrum



	% Wt.
Carbon	66.0
Oxygen	26.68
Calcium	4.20
Potassium	2.32
Magnesium	0.80

Fig. 6 Orange peel SEM images and EDX analysis

orange peel [16]. Lignin is a complex phenolic polymer of cellulose, hemicellulose and pectin components that fills the voids in wood cell walls. It fills the spaces in vascular and supporting tissues, such as xylem tracheids, vascular elements and scleid cells [28]. The SEM image shows that the cell walls of the GOP are tightly bound with lignin (Fig. 6).

Acoustic Absorption of Green Composite Soundproofing Material

To determine the sound insulation performances, 10 Hz, 100 Hz and 1 kHz frequencies were chosen, since > 100 dB sound pressure is provided. For 10 Hz, 100 Hz and 1 kHz according to the GOP amount of the sound insulation materials produced from orange peel, the highest sound absorption performance was observed as 26%, 17.1% and 37.5% in OP-20, respectively (Fig. 7a). When the sound absorption capacities are examined according to the different resin type and amount used in the production of sound insulation materials, when both resin types are used in equal amounts, the produced material showed the highest sound absorption performance at all three frequencies (Fig. 7b).

Characterization of Green Composite Soundproofing Materials

Characterization analyzes and tests were applied to determine the effect of resin types on composite sound insulation materials. The O–H band at 3300 cm^{-1} is due to lignin and moisture. In VA-40, the O–H band has become widespread due to its vinyl structure. The amplitude of the C–H band decreased at approximately 2900 cm^{-1}. The O–H stretch of the 1160 cm^{-1}–1180 cm^{-1} peak was caused by the styrene structure in the acrylic resin. The lignocellulosic structure shown in Fig. 5 was detected in composite sound insulation materials. The C–C stretching peak observed from 600 cm^{-1}

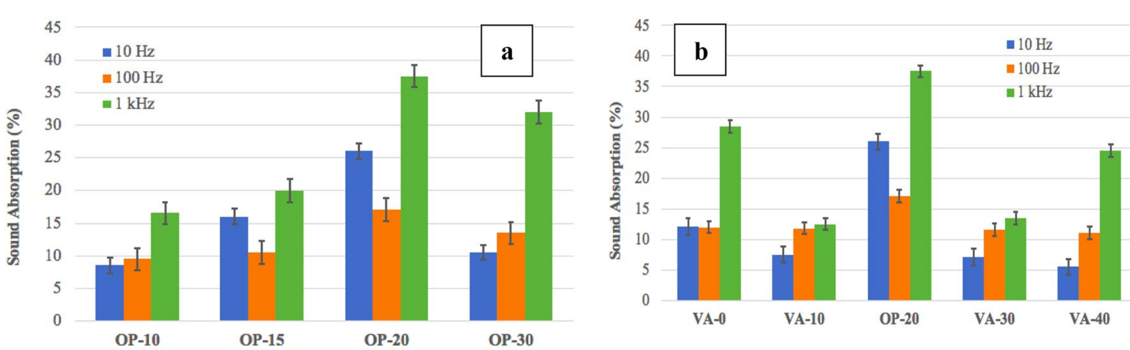


Fig. 7 Sound absorption performances of green composite sound insulation materials

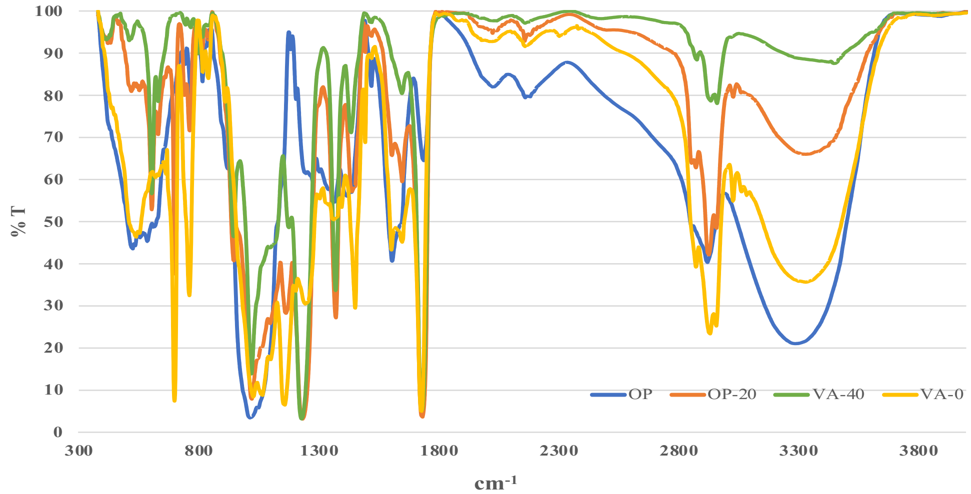
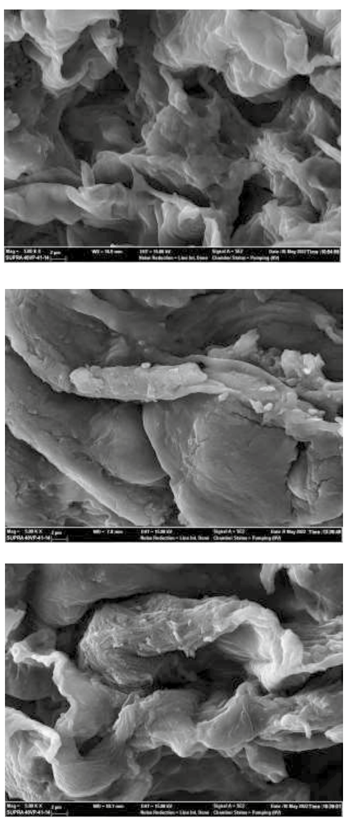


Fig. 8 FT-IR spectra of green composite sound insulation materials



OP-20	% Wt.
Carbon	58.39
Oxygen	39.60
Chlorine	1.11
Potassium	0.50
Sodium	0.30
Suphur	0.11

VA-0	% Wt.
Carbon	55.52
Oxygen	41.53
Chlorine	1.69
Potassium	0.94
Magnesium	0.08
Sodium	0.25

VA-40	% Wt.
Carbon	55.77
Oxygen	41.60
Chlorine	1.33
Potassium	0.58
Magnesium	0.15
Sodium	0.37
Suphur	0.19

Fig. 9 EDX analyzes and SEM images of green composite sound insulation materials

to 500 cm^{-1} [29] caused a strong peak to occur at 600 cm^{-1} due to the styrene structure found in ASA (Fig. 8).

SEM images of OP-20, VA-0 and VA-40 sound insulation materials are given in Fig. 9. No gaps were observed in VA-0 due to the styrene effect. In VA-40 material, on the other hand, the vinyl structure has enabled the formation of large gaps. Due to the cross-links formed by AVA and ASA resins in OP-20, the size of the gaps decreased compared to VA-40, but more gaps were observed in OP-20. According to the EDX analysis results, the sulfur determined in OP-20 and VA-40 materials was observed to originate from the AVA resin.

Soundproofing materials consist of channels, cracks or gaps (numerous interconnected pores of small diameter) that allow sound waves to enter the materials [5, 7]. The porosity and curvature of sound absorbing materials converts the sound wave into thermal energy [1]. The sound wave (sound energy) is dispersed by the thermal loss due to friction in the pore walls of the air molecules and the viscous loss brought by the viscous air flow within the material. The sound absorption of porous materials with a wide frequency band constitutes the sound energy consumption principles. Small pores increase the sound energy consumption by further improving the connection between macro-sized pores [5]. The sound absorption coefficient generally varies depending on the material type and the applied frequency, and materials with an average sound absorption coefficient value greater than 0.2 can be called sound absorbers [30]. Although the sound absorption coefficient is weak in the low frequency range, it has fine acoustic isolation properties in the high frequency exchange [31].

Physical and Mechanical Properties of Green Composite Sound Insulation Materials

It was determined that the density (0.33 g/cm^3) (Fig. 10a) and shrinkage ratio (16.25%) (Fig. 10b) of VA-40 composite sound insulation material were the highest among other materials. Due to the vinyl structure in AVA, the shrinkage rates of the materials have increased. It has been determined that the densities of the materials are approximately the same.

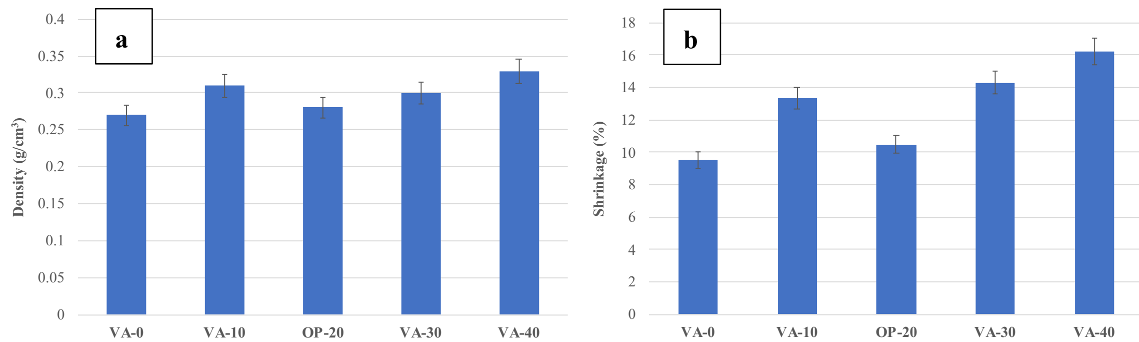


Fig. 10 Density (**a**) and shrinkage ratios (**b**) of green composite sound insulation materials

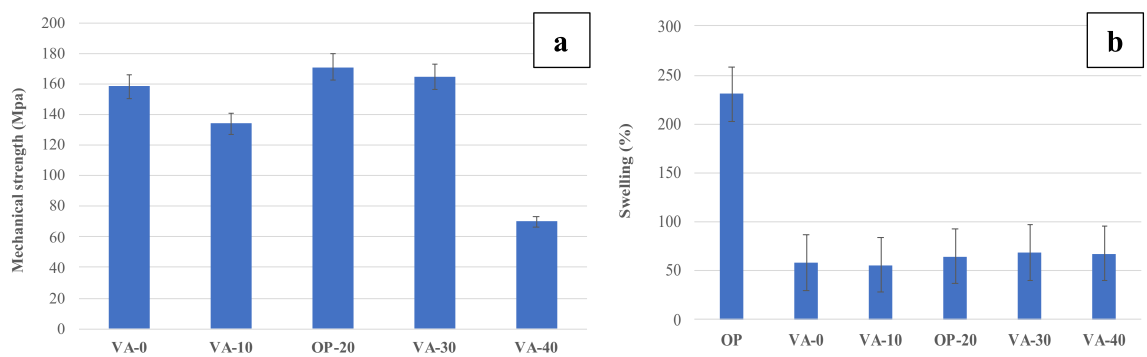


Fig. 11 Mechanical strengths (**a**) and swelling ratios (**b**) of green composite sound insulation materials

Swelling rate of dried orange peel (OP) was determined as 230%. It was observed that the swelling ratio of the composite material increased as the amount of AVA increased. The highest swelling rate of 67.79% was found in VA-40.

It has been observed that the styrene structure in ASA increases the mechanical strength of composite materials. The mechanical strength of OP-20 was determined as 170.97 MPa (Fig. 11a). In VA-40, where the styrene structure is dense, the mechanical strength is 158.28 MPa (Fig. 11b). It has been observed that mechanical strength is higher in OP-20 material due to the cross-links formed by AVA and ASA resins.

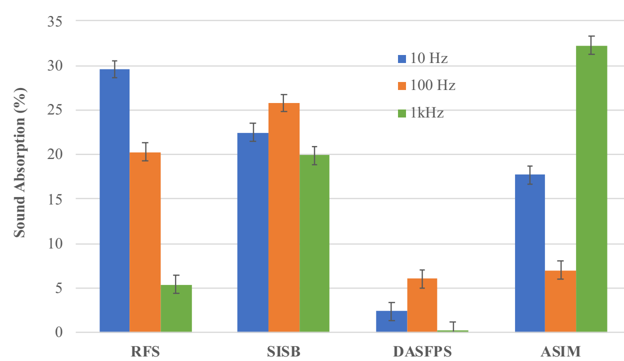


Fig. 12 Sound absorption performances of commercial sound insulation materials

Acoustic Absorption of Commercial Soundproofing Materials

The sound absorption performances of commercial sound insulation materials called auto sound insulation material (3 mm thickness), Decibel Acoustic Sponge Fireproof Pyramid Sponge, Sound Insulation Sponge Bondex (50 mm thickness), Rubber floor sponge were compared. At 10 Hz frequency, the highest sound insulation (29.61%) was observed in the rubber floor sponge. At 100 Hz frequency, the highest sound insulation (25.81%) was found in Bondex sound insulation sponge and the highest sound insulation (32.27%) at 1 kHz frequency was found in auto sound insulation material. The lowest sound insulation in all three frequencies was determined in Decibel Acoustic Foam Fireproof Pyramid Foam (Fig. 12).

The highest sound absorption performance of the sound insulation materials produced from orange peel for 10 Hz, 100 Hz and 1 kHz, respectively, was observed as 26%, 17.1% and 37.5% in OP-20. OP-20 exhibited similar properties with commercial sound insulation materials.

Conclusion

It is aimed to design and develop cost-effective green composite sound insulation materials produced using orange peels and commercial acrylic resins as agricultural waste. The developed porous sound insulation material exhibited similar performance to commercial sound insulation materials at low frequencies. It is proof that the cavities in the structure of the material are capable of absorbing sound energy. Since the production costs of porous sound absorbing materials are cheap, their usage areas are increasing day by day. The developed green composite sound absorbers were produced very cheaply, because they were produced using orange peel and commercial acrylic resins, which are in the category of free waste. More studies should be done on the usability of this developed material for practical purposes outside the laboratory. As a result, farmers living in rural areas will use their agricultural wastes for insulation purposes instead of burning them, creating employment in a new area and saving a significant amount of energy. The developed green composite insulation material is a candidate for commercialization in the future.

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Data availability Data are available on request due to privacy or other restrictions.

Declarations

Conflict of Interest The authors declare no conflicts of interest.

References

1. Hariprasad K, Ravichandran K, Jayaseelan V, Muthuramalingam T (2020) Acoustic and mechanical characterisation of polypropylene composites reinforced by natural fibres for automotive applications. J Mater Res Technol 9(6):14029–14035. https://doi.org/10.1016/j.jmrt.2020.09.112
2. Raj M, Fatima S, Tandon N (2020) Recycled materials as a potential replacement to synthetic sound absorbers: a study on denim shoddy and waste jute fibers. Appl Acous 159:107070. https://doi.org/10.1016/j.apacoust.2019.107070
3. Othmani C, Taktak M, Zein A, Hentati T, Elnady T, Fakhfakh T, Haddar M (2016) Experimental and theoretical invest igation of the acoustic performance of sugarcane wastes based material. Appl Acous 109:90–96. https://doi.org/10.1016/j.apacoust.2016.02.005
4. Buratti C, Belloni E, Lascaro E, Merli F, Ricciardi P (2018) Rice husk panels for building applications: thermal, acoustic and environmental characterization and comparison with other innovative recycled waste materials. Constr Build Mater 171:338–349. https://doi.org/10.1016/j.conbuildmat.2018.03.089
5. Cao L, Fu Q, Si Y, Ding B, Yu J (2018) Porous materials for sound absorption. Comp Commun 10:25–35. https://doi.org/10.1016/j.coco.2018.05.001
6. Yun BY, Cho HM, Uk Kim Y, Lee SC, Berardi U, Kim S (2020) Circular reutilization of coffee waste for sound absorbing panels: a perspective on material recycling. Environ Res 184:109281. https://doi.org/10.1016/j.envres.2020.109281
7. Taban E, Khavanin A, Ohadi A, Putra A, Jafari AJ, Faridan M, Soleimanian A (2019) Study on the acoustic charac teristics of natural date palm fibres: experimental and theoretical approaches. Build Environ 161:106274. https://doi.org/10.1016/j.buildenv.2019.106274
8. Hee Or K, Putra A, Selamat MZ (2017) Oil palm empty fruit bunch fibres as sustainable acoustic absorber. App Acous 119:9–16. https://doi.org/10.1016/j.apacoust.2016.12.002
9. Gadea Borrell JM, Juliá Sanchis E, Segura Alcaraz J, Montava Belda I (2020) Sustainable sound absorbers from fruit stones waste. App Acous 161:107174. https://doi.org/10.1016/j.apacoust.2019.107174
10. Pedroso M, de Brito J, Silvestre JD (2017) Characterization of eco-efficient acoustic insulation materials (traditional and innovative). Constr Buil Mater 140:221–228. https://doi.org/10.1016/j.conbuildmat.2017.02.132
11. https://www3.weforum.org/docs/WEF_Annual_Report_2020_21.pdf
12. Liuzzi S, Rubino C, Martellotta F, Stefanizzi P, Casavola C, Pappalettera G (2020) Characterization of biomass-base d materials for building applications: The case of straw and olive tree waste. Indust Crops Prod 147:112229. https://doi.org/10.1016/j.indcrop.2020.112229
13. De Carvalho PS, Nora MD, Da Rosa LC (2020) Development of an acoustic absorbing material based on sunflow er residue following the cleaner production techniques. J Clean Prod 270:122478. https://doi.org/10.1016/j.jclepro.2020.122478
14. (FAOSTAT) Food and agriculture organisation of the United Nations statistical database; Statistical division, FAO, Rome, Italy (2021), http://www.fao.org/statistics/en/
15. Leo CH, Lee CP, Foo SY, Wee Tan JC, Tan JD, Ong ES, Hashimoto M (2022) 3D printed nutritious snacks from orange peel waste. Mater Today. https://doi.org/10.1016/j.matpr.2022.08.484
16. Singh PP, Nath G (2021) Processing of Orange Peel Biomass waste of Juice Industries and Valorization to Smart Acoustic Material. Res Square. https://doi.org/10.21203/rs.3.rs-724241/v1
17. Carranza-Méndez RC, Chávez-González ML, Sepúlveda-Torre L, Aguilar CN, Govea-Salas M, Ramos-González R (2022) Production of single cell protein from orange peel residues by Candida utilis. Biocat Agric Biotech 40:102298. https://doi.org/10.1016/j.bcab.2022.102298
18. Terzioğlu P, Güney F, Parın FN, Şen İ, Tuna S (2021) Biowaste orange peel incorporated chitosan/polyvinyl alcohol composite films for food packaging applications. Food Pack Shelf Life 30:100742. https://doi.org/10.1016/j.fpsl.2021.100742
19. Maderuelo-Sanz R, García-Cobos FJ, Sánchez-Delgado FJ, Mota-López MI, Meneses-Rodríguez JM, Romero-Casado A, Acedo-Fuentes P, López-Ramos L (2022) Mechanical, thermal and acoustical evaluation of biocomposites made of agricultural waste for ceiling tiles. Appl Acous 191:108689. https://doi.org/10.1016/j.apacoust.2022.108689
20. Balbay S, Acikgoz C (2022) New method for producing carbon foam from recycled carbon (NEWCAFO). J Mater Cycles Waste Manag. https://doi.org/10.1007/s10163-022-01470-1

21. Doğru T, Pulat E (2020) Otomotıvde Kullanılan Elyaflı Malzemelerın Akustık Özellıklerının Incelenmesı. Uludağ Üniversitesi Mühendislik Fakültesi Dergisi. https://doi.org/10.17482/uumfd.703588
22. Kinsler LE, Frey AR, Coppens AB, Sanders JV (1982) Fundamentals of Acoustics. J Acoust Soc Am 72(3):1090. https://doi.org/10.1121/1.388211
23. ASTM E2611 (2019) Standard Test Method for Normal Incidence Determination of Porous Material Acoustical Properties Based on the Transfer Matrix Method, ASTM International, West Conshohocken, PA
24. Awad SA (2021) Swelling, thermal and mechanical characterizations of high-density polyethylene/recycled biochar composites. JOTCSA 2011 8(4):1137–1144. https://doi.org/10.18596/jotcsa.984583
25. Ayala JR, Montero G, Coronado MA, García C, Curiel-Alvarez MA, León JA, Sagaste CA, Montes DG (2021) Characterization of orange peel waste and valorization to obtain reducing sugars. Molecules 26:1348. https://doi.org/10.3390/molecules26051348
26. Al-Saadi NHM, Ahmad, NS, Sa´eed, SE (2009) Determination of some chemical compounds and the effect of oil extract from orange peel on some pathogens. J Kerbala Univ. 7(2) Scientific
27. Zapata B, Balmaseda J, Fregoso-Israel E, Torres-Garcı´a E (2009) Thermo-kinetics study of orange peel in air. J Therm Anal Calorim 98:309–315. https://doi.org/10.1007/s10973-009-0146-9
28. Ruan J-Q, Li Z, Xie K-Y, Guo W, Fei C, Lu M-H, Yang H (2022) Multifunctional cellulose wood with effective acoustic absorption. AIP Adv 12:055102. https://doi.org/10.1063/5.0078482
29. Tiryaki B (2013) Activated carbon production from cellulose, hemicellulose and lignin. Master Thesis. Ankara University
30. Selvaraj S, Ramalingam S, Parida S, Rao JR, Nishter NF (2021) Chromium containing leather trimmings valorizati on: sustainable sound absorber from collagen hydrolysate intercalated electrospun nanofibers. J Hazar Mater 405:124231. https://doi.org/10.1016/j.jhazmat.2020.124231
31. Tang X, Yan X (2017) Acoustic energy absorption properties of fibrous materials: a review. Composites 101:360–380. https://doi.org/10.1016/j.compositesa.2017.07.002

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