Composite Materials that are Good Sound Absorbers

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As a consequence of the accelerated development of science and technology, noise pollution is one of the biggest problems of modern society. The most common method for reducing noise pollution is the use of sound - absorbing materials, sound insulation materials, and noise damping materials. This paper aims to provide a review of composite materials that have been shown to be good sound absorbers. Which include composites made of synthetic, natural and recycled materials. The advantages and disadvantages of synthetic fibres and natural fibres were also studied. The influence of individual components, such as porosity, density, thickness, in composite materials on the sound absorption characteristic is also shown.

Keywords: composite materials, noise control, sound absorption, recycled materials

1. INTRODUCTION

In recent decades, we have witnessed a scientific and technical revolution. Due to this revolution, there are various factors that have a strong influence on everyday human life. As a result, environmental pollution is one of the biggest problems of modern society. Noise pollution poses a real threat to the health and welfare of people.

Under pollution, noise means any unwanted sound. Noise, although it has the same physical characteristics as sound, differs from sound in that it causes different psychophysiological effects and harmful effects on human health. The effect of noise can be an auditory effect, limited to the hearing organ and extra charge effect, an effect on other organs and functions of the human body [1]. The sound volume of 120 to 150 dB causes severe disturbances, but even 70 dB sound can cause side effects. Frequent noise exposure affects stress and emotional stability. Noise also affects the living world, sound is important in the communication of animal species and has a significant place in the balance of ecosystems.

Environmental pollution with noise is a common problem in urban areas, and is caused by a wide range of noise sources, from vehicles in traffic, through restaurants, concert halls, all the way to factory plants and means of work. The biggest noise comes from machines and traffic, especially cars, trucks, planes. Construction, mining, agricultural machines and machines in factories create noise. Noise cannot be eliminated, but it can be reduced by traffic regulation, insulated walls, application of personal protective equipment, etc. Due to the extreme harmfulness of exposure to excessive noise, it is necessary to control noise and apply appropriate protection measures. Noise control can be performed at the noise source (active noise control), on the transmission routes and at the place of reception (passive noise control). From the population of sound propagation, there are materials that transmit, absorb or reflect sound. This is important when choosing materials for the construction of plants, machines, devices.

The use of sound-absorbing materials is one of the effective noise control technologies. Sound-absorbing materials absorb most of the sound energy while reflecting a very small part of the sound energy. They are used in various locations: near noise sources, on various transmission routes, and sometimes near receivers. There is a wide range of sound-absorbing materials; which provide absorption properties that depend on frequency, composition, thickness and surface area. However, materials that have a high value of the sound absorption coefficient are usually porous. Composite materials are an important part of noise protection solutions due to the properties that make them suitable for use in passive noise control devices. The properties of composite materials can be controlled and optimized based on the application of interest by adding reinforcing materials. In the rapidly growing technological world, composite materials are a unique promising material.

2. SOUND ABSORBING MATERIALS

Sound-absorbing materials are materials that reduce the acoustic energy of a sound wave as the wave passes through the material. Sound absorptive materials typically have a soft, porous structure, offer only low resistance to a sound wave, and reduce the acoustic energy of a sound wave as the wave passes through it by the phenomenon of absorption. To be an efficient sound absorber, a material usually will convert acoustic energy to some other form of energy, usually heat. The main reasons for the acoustic energy losses when sound passes through the sound - absorbing materials are due to mentum losses, frictional losses, and temperature fluctuations. According to the mode of sound absorbers, they can be divided into porous, resonator and panel absorbers.

A porous absorbent material is a solid that contains cavities, channels, or interstices, so that sound waves can enter through them. According to the macroscopic configurations, sound absorbing materials can be classified into two types, the first type is called ‘closed pores’ and the second type is called ‘open pores’. Closed pores are substantially less efficient than open pores in absorbing sound energy, but they have an effect on some macroscopic properties of the material such as its bulk density, mechanical strength and thermal conductivity. Open pores have a continuous channel of communication with the external surface of the body, and they have a great influence on the absorption of the sound [2]. Porous sound - absorbing materials can also be classified based on their microscopic configurations as cellular, fibrous, or

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granular. In these materials, absorption occurs by causing the sound waves to activate the motion of the fibres, membranes and the air in the spaces surrounding the fibres or voids. Frictional energy losses generate heat, which is dissipated, thereby reducing the acoustic energy [2]. It is known that there are several parameters that may influence the sound losses, such as thickness, density, porosity or flow resistance, coefficient of elasticity.

Absorption materials are characterized by a sound absorption coefficient that defines the ability of a material to absorb and transform part of the energy of sound into another form [1]. The absorption coefficient is a useful concept when using geometrical acoustic theory, especially to evaluate the decay and growth of sound energy in a room. However, when sound is considered as a wave motion, it is necessary to use the concept of acoustic impedance.

3. COMPOSITES THAT ARE GOOD SOUND ABSORBERS

The application of composite materials in noise control is of great importance, because the properties of composite materials can be controlled and optimized based on the application of interest by adding reinforcement. Each composite material absorbs sound at a certain frequency which is characteristic of the properties of that material [3]. Natural, synthetic and recycled materials can be used as sound absorbers. Hemp, bamboo, coconut, cotton, kenaf, rice, wheat fibres are examples of natural sound absorbers. Synthetic materials such as ceramics, mineral fibres glass wool are used in noise control as absorption materials. Composite material technology provides the possibility of using hazardous waste materials in useful materials that can be used in noise control.

Composite absorption materials are a good solution to the noise problem. Therefore, these composites play a crucial role in the automotive and aerospace industries, medicine and other areas where noise pollution significantly affects human health. With the different types of composite materials currently available, it is possible to cover a wide frequency range [3].

3.1. Synthetic composite materials

Synthetic composite materials have proven to be effective sound absorbers. Availability of materials of known properties, low production cost make synthetic materials suitable for passive noise control. The most commonly used sound absorbers and insulation materials are glass wool, polyurethane foam, mineral wool and their composites, but although they have good sound insulation properties, they have disadvantages such as risks to health and pollution of the workplace and environment [4]. The sound absorption characteristics of glass fibre materials, in the norm, are excellent, but increasing density may improve barrier characteristics, but will also decrease absorption. The acoustic properties of many composites are tested, such as composites based on aluminium, cement, ceramics.

Different types of aluminium composites are used in noise control. Aluminium foam, the material of the future, has modified properties obtained by combining the properties of the metal and the cell structure [5]. Such modified properties cannot be achieved by any of the conventional properties of aluminum. Aluminium foam is a metal with a cellular structure that contains more than 70% of pores. The pores can be closed (closed cell foam) or interconnected (open cell foam). Aluminium foams, especially those with interconnected pores, absorb sound very efficiently, incoming sound is mixed between the pores inside the foam, the pore surfaces vibrate, resulting in the transformation of sound energy into heat. Fero Simancik et al. [5] examined the absorption properties of aluminium foam of different densities in relation to the absorption properties of PU foam and fiberglass mats. Lower density aluminium foam showed better sound absorption in the frequency range below 1000 MHz, while higher density aluminium foam showed better performance in the 4000-5000 MHz range. Low-density aluminium foam has a better effect in sound absorption. The advantages of using aluminium foam are reflected in the fact that it is not flammable, does not erode under air currents and vibrations and can be easily cleaned if it is contaminated with dust, it is also more environmentally friendly compared to glass wool, polyurethane foam.

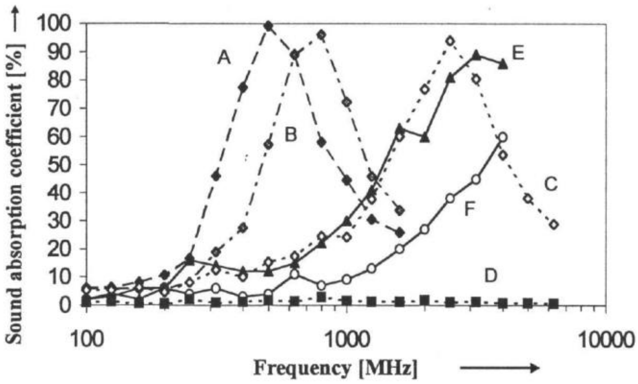

Figure 1: Sound absorption coefficient of aluminium foam at various thickness of the air gap between the sample and the solid background (A = 40 mm, B = 20 mm, C = 0 mm), compared with bulk aluminium (D) and glass fibre mat (F) [5]

Porous ceramics have a wide range of applications, including the fabrication of filters, membranes, sensors, supports, biomedical and building materials. Microstructures such as porosity and pore size distribution are very important factors for many potential applications of porous ceramics. The development of porous ceramics as external building materials will provide ceramic tiles not only with the production of light constructions but also with other functions such as insulation, workability and sound absorption. In the field of acoustic absorption, porous ceramic-absorbent structures can have other important properties in addition to sound absorption, such as resistance to high temperature, resistance to chemicals. Zhang et al., examined the acoustic properties of porous ceramics obtained by gel casting production. In this process, a precipitate of ceramic powder and N2 bubbles, formed from a separate canister containing a surfactant before the precipitate forms is mixed in a spiral mixer [6]. They compared the sound absorption of porous ceramics obtained by the new method and the conventional method with a dense ceramic tile. The results showed that porous ceramics obtained by the new method have the highest degree of absorption, while purchased dense ceramics have a low coefficient of absorption. Porous ceramics obtained by the new and conventional method showed good sound absorption, in the frequency range between 5000-6000 Hz, where porous ceramics obtained by the new method have an absorption coefficient of 0.7, while conventional porous ceramics have an absorption coefficient of 0.5. Porous ceramics produced by the new method show a higher total porosity, which results in the expected increase in the sound absorption coefficient [6]. Giese et al. [7] obtained porous ceramics by freeze gelation process, they also used expanded perlite as a melting phase to form pores. Expanded perlite is a great example of inorganic glass fillers that create pores and at the same time act as a reinforcing material. Compared to traditional dense ceramics, porous ceramics showed a high absorption coefficient. Porous ceramics showed better acoustic performance in the range of 400-800 Hz, with an absorption coefficient greater than 0.6. Porous ceramics have good acoustic performance due to low resistance to airflow [7]. Because airflow resistance can be adjusted over a wide range, the material is useful for many applications.

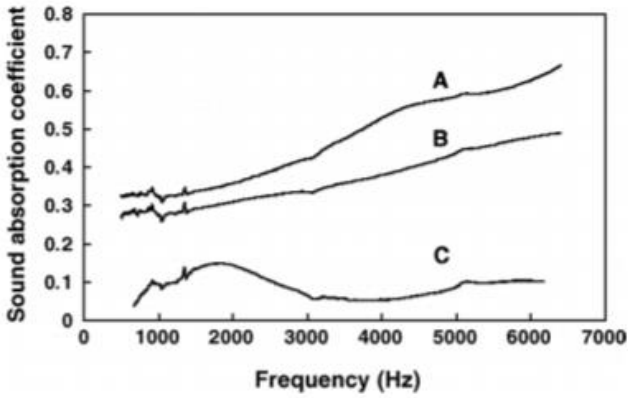

Figure 2: Sound absorption as a function of frequency for the porous ceramics fabricated by the new method (A) and the conventional method (B), and the dense ceramic tile bought from the market (C) [6]

Aerogel is one of the lightest known hard materials. It is a silicate solid that contains 99.8% air. Aerogels are also known as frozen smoke and for them, it is claimed to be the best thermal insulators ever made, as they are 40 times better than conventional fibreglass insulation materials [8]. Several raw materials have been used to produce aerogels, but silica aerogels are the most common. Recent research has focused on the use of aerogels in granular form as sound-absorbing materials. Donga et al. [9] investigated the acoustic properties of composite aerogel with different concentrations of silicon dioxide and polydimethylsiloxane, which reduce the rigidity of the material. Such composite aerogels have pore sizes between 5-20 nm, and experimental results have shown that these materials show better sound absorption properties than commercial fibreglass. Silicon aerogel composites with 40% polydimethylsiloxane showed a high absorption coefficient in the range of 800-1000 Hz. Unfortunately, aerogel production is still expensive, but it is very likely that advances in materials science will reduce the cost of aerogel production, which could lead to their widespread use in the construction and automotive industries in the near future.

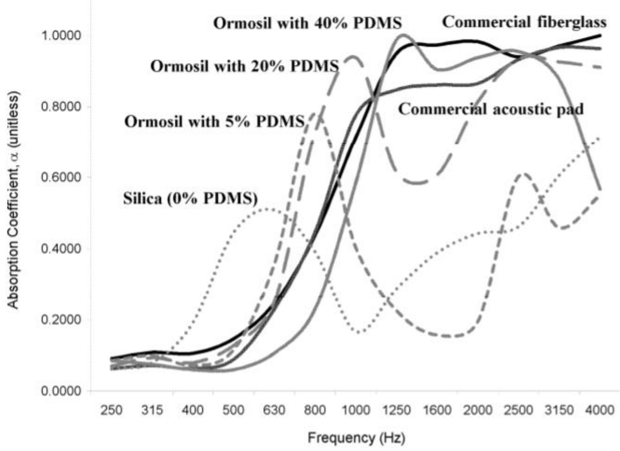

Figure 3: Adsorption coefficient as a function of the acoustic frequency. Silica/PDMS ormolus (with varying concentrations of PDMS) are compared with commercially available acoustic insulators [9]

Although the production of metal foams, ceramics and aerogels can contribute to greenhouse gas emissions, these materials simultaneously have high structural strength and reduced structural weight, and their use in the aerospace industry has the potential to reduce fuel consumption and save energy. Although harmful to human health and the environment, the advantages of using synthetic materials over natural fibres are reflected in better mechanical properties and the fact that synthetic fibres have a low resistance to moisture absorption [4].

3.2. Natural composite materials

Natural fibre composites are increasingly used in the construction and automotive industries. The wide application of natural materials is reflected in their minimal impact on human health and the environment. Although it is often emphasized that the mechanical properties of natural materials are inferior to synthetic materials, composites based on natural fibres compensate for these shortcomings in other aspects. Natural fibre composites are renewable, non-abrasive, cheaper, more numerous and do not present a great risk to human health and are safer during handling and processing [4]. The acoustic properties of different types of natural fibres such as: cotton, kenaf, hemp, flax, bamboo, rice, coconut, etc. are examined.

Kenaf is the name of the hibiscus plant related to fibres of jute and cotton and shows similar characteristics. Stems produce two types of fibres, coarser in the "bast", and finer in the "core".Bast fibres (about 35%) are suitable for making paper, textiles and rope; the core (about 65%) is usually used as biomass or can be reduced to particles and bonded into panels similar to particleboard. D'Alessandro and Pispola [10] examined the acoustic properties of a kenaf sample. Kenaf samples show an average absorption coefficient of 0.85 in the range 500-5000 Hz and 0.65 in the range 100 - 5000 Hz. Although their performance appears to be slightly lower than that of traditional fibre absorbers, these materials can be considered a valid alternative to traditional mineral wool covers for thermoacoustic applications, given their low environmental and human impact [10]. The sound and mechanical properties of kenaf can be improved using composite technology. This acoustic material provides the possibility to be used as a sound absorber covering a wide frequency range when incorporated into other composites [4].

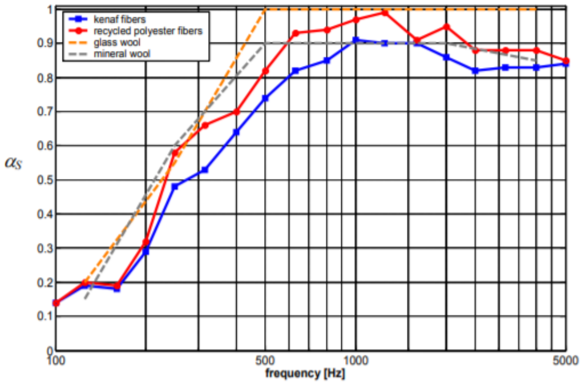

Figure 4: Third-octave band sound absorption coefficient of kenaf in comparison with traditional fibrous absorber [10]

Hemp is a significant source of fibre for both the textile and many other industries. Hemp is used to making ropes, bags, paper, such as filter, cigarette, painting paper, etc. Hemp fibres are also used to treat wastewater and soil. Lukić et al. [11] examined the acoustic properties of hemp composites with different polypropylene content. The composite was formed by alternating layers of hemp and polypropylene, where the amount of polypropylene ranged from 10 to 40% of the total mass. The best result was achieved for a composite with 20% polypropylene, where the absorption coefficient of 82% was measured in the frequency range of 2000-4000 Hz. Composites with a higher polypropylene content should be used to attenuate lower frequencies [11]. Markiewicz et al. [12] also examined the acoustic properties of hemp and polypropylene composites. By measuring in an impedance tube, they concluded that pure polypropylene composites without the presence of hemp show very poor sound absorption in the frequency range from 0 to 7000 Hz. Hemp composites showed good absorption properties in the frequency range of 3000 to 6000 Hz, while in the region below 3000 Hz there is no improvement compared to pure polypropylene composites [12]. The produced composites have good acoustic properties thanks to their porous structure. Hemp-based composites show good absorption properties at frequencies higher than 1500 Hz, which is why they have found application in the automotive industry.

Apart from the production of conventional textile products, flax is also used for the production of technical textiles. Flax fibre is used in automotive industry, paper industry, production of protective textiles, construction industry and in the production of composites. Namely, flax fibre has all the desirable properties required for the manufacture of composite materials: relatively high heat resistance and hardness, low tendency to deformation, low density. Yang and Yan [13] examined the acoustic properties of flax and its epoxy composites and compared the results with synthetic fibres. At frequencies above 1000 Hz the absorption coefficient of flax is 0.8 while the values for glass and carbon fibres are generally lower than the values of natural fibres. Flax fibres have superior sound absorption properties than synthetic fibres such as glass and carbon fibres due to their unique porous and multiple structures [13]. Flax fibre reinforced composites also had better sound absorption behaviour than synthetic fibre reinforced composites, especially at high frequencies, which could be very useful for aerospace applications. Lee et al. [14] compared the sound absorption behaviour of flax/epoxy composites compared to glass/epoxy composites. Sound absorption is small at frequencies below 500 Hz, while absorption gradually increases at higher frequencies and is relatively constant at frequencies from 3150 to 6300 Hz, with an absorption coefficient of 0.3 [14]. The absorption values of the flax/epoxy composite compared to the results of Yang and Yan [13], where the woven flax fibers had a high absorption coefficient, are low. Due to the production process of composite samples, the density increases, which results in a decrease in the free space between the flax fibres, while the sound absorption performance of epoxy is generally poor. The results show that flax/epoxy composites have good acoustic properties and that there are ways to improve their acoustic properties, for example by adding additives such as calcium carbonate, which would increase the stiffness of the composites and provide better absorption of sound waves [14].

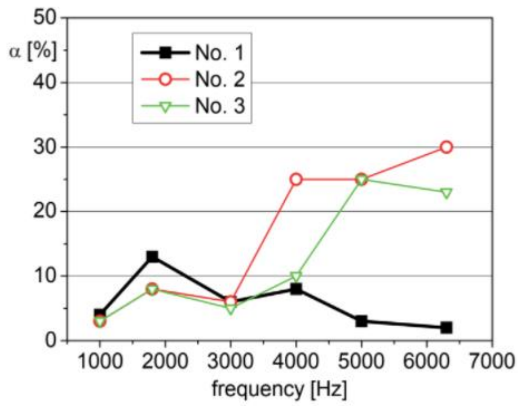

Figure 5: Frequency dependences of sound absorption coefficient for the different samples [12]

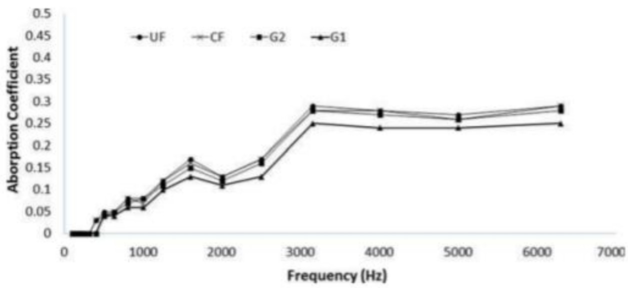

Figure 6: Sound absorption coefficients of samples at different frequencies [14]

In addition to various applications in everyday life, coconut fibre has proven to be one of the strongest lingocellulosic material in sound absorption [4]. With the help of composite technology, coconut fibers can be processed into efficient sound absorbers for various industrial applications. Researchers examined the effects of porous layer backing and perforated plates on the sound absorption coefficient using coconut fibres [15]. Coconut fibre thickness of 20 mm without porous substrate has a maximum value of noise absorption coefficient in the frequency range 3680-3860 Hz. The porous layer backing can improve the noise absorption coefficient at low and high frequencies. A 20 mm thick coconut fiber layer with a porous layer backing shows the maximum noise absorption values in the frequency range with an absorption coefficient of 0.97. Coconut fibre with a perforated plate gives a higher value for lower frequencies in the range of 600-2400 Hz. The absorption coefficient of noise coconut fibres was increased with the backing with a woven cotton cloth. This is because the substrate of the porous layer has a higher flow resistance than coconut fibres, so that sound can be significantly dissipated as it travels through the material [15]. Mahzan et al. [16] used coconut fiber composites for reinforcement, recycled rubber as secondary material and polyurethane as a bonding material for acoustic panels. The sample with the maximum porosity value showed an absorption coefficient of 0.9 in the frequency range close to 1500 Hz [16]. The acoustic absorption of this composite is improved as a result of the increase in porosity when coconut fibres are used as a reinforcing element in this composite. All these results lead to the need for further development of coconut fibre materials for industrial applications in a wide range of frequencies.

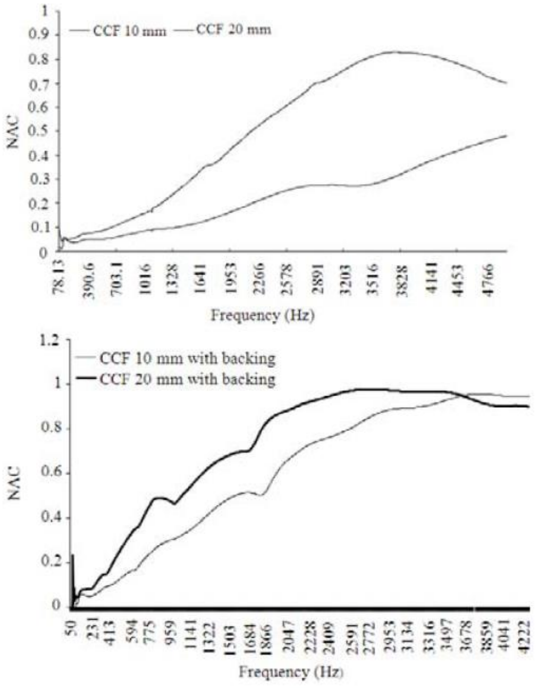

Figure 7: The noise absorption coefficient of coconut coir fiber without/with porous layer [15]

Natural fibres have great potential to be used as a sound-absorbing material. Due to the increasing pollution of the environment, there is increasing use of environmentally friendly, natural materials. Therefore, manufacturers of sound-absorbing materials tend to change their main components of products containing asbestos-based materials with natural fibres. These new fibres are much safer and pose fewer problems for human health and the environment. With the development of the industry, there are questions related to global warming caused by the emission of greenhouse gases into the atmosphere. The materials industry and the manufacturing industry can have a lot of influence on the change of course in the market of acoustic materials. Therefore, research on acoustic materials is important and should be increased, especially those based on renewable resources that can lead to sustainable alternatives to conventional materials for future and current applications. These achievements include the use of natural fibres, recycled polymers and bio-based polymers, porous metals, new composites and smart materials.

3.3. Recycled composite materials

Continuous increase in pollution and considering environmental protection tends to the need to develop alternative materials for sound attenuation. In order to protect the environment and mitigate noise from industry and urban transport, many new noise control materials have been developed as alternatives to traditional (glass or stone wool); these materials can be made from recycled materials such as rubber, plastics, agricultural waste, recycled textile fibres, etc.

In the case of industrial waste in the last few years, the disposal of used car tires has become one of the main environmental problems. The amount of waste tires is increasing due to the high demand for tires and their short service life. Therefore, it is necessary to improve or develop a certain procedure for the application of recycled waste tires. Nowadays, many ways of waste rubber management have been proposed and it is classified into three groups, ie. energy reuse, recycling, remondelling and recovery. In countries where the problem of used tires is solved in a safe way, part of the used tires is processed into semi-finished and finished products and used as an energy source. The use of recycled rubber to produce sound absorbers or resilient substrates can solve two environmental problems, noise and environmental pollution. Hong et al. examined the acoustic properties of a recycled rubber composite material. The composite absorber has a layer upon layer structure with the rubber particles as the bottom layer, on the top of which is a single or multiple layers of polymer porous foam or perforated panel [17]. It was found that the layer of recycled rubber particles has a higher sound absorption coefficient than porous materials that absorb the sound of the same thickness in the low-frequency range. In the rubber particle layer, two main mechanisms affect the reduction of sound energy: viscous losses due to friction between air and particles, and the friction between particles. It should be understood that the functional area of sound absorption shifts to the high-frequency side as the layer of PU foam becomes thicker and the sound absorption at higher frequencies is relatively small [17]. Radičević and Ristanović [18] presented the initial results of research on the absorption properties of materials made on the basis of recycled rubber granules. Samples of red and black rubber, different thicknesses and different granule structures were examined. The red rubber material has a higher absorption coefficient in the frequency range below 1000 Hz, while the maximum absorption coefficient of 0.9 has a black rubber at a frequency of 1000 Hz. Based on the measurement of the absorption coefficient of recycled rubber materials, it has been determined that these materials have a high level of absorption in the medium frequency range [18]. As such, they have a wide range of applications, thus solving environmental pollution with rubber waste by converting rubber waste products into sound absorbers to reduce noise.

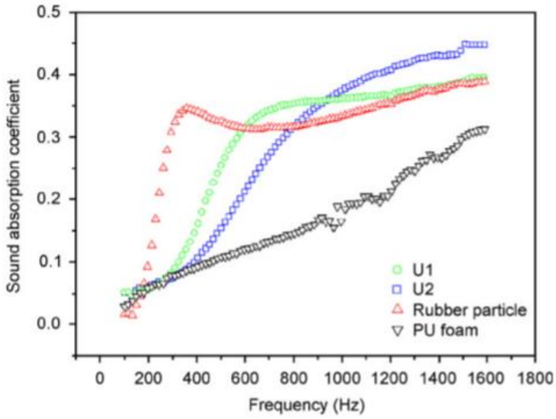

Figure 8: The absorption spectra for double-layer structures of rubber particles with porous foam materials [17]

Foams are widely used as sound-absorbing materials in noise control engineering. These sound-absorbing materials are used to control noise and vibration in many mechanical systems, including industrial machinery, household appliances, vehicles and buildings. Foam is a solid substance that contains cavities, channels or interstices so that sound waves can enter through them. One of the residues of production processes in the textile industry is polyurethane foam, so the recycling of these residues prevents the foam from going to a landfill, which is a serious environmental risk. Recycled polyurethane foam is often used in the production of carpet mats, cushion inserts for footwear, furniture, packaging materials, thermal insulation boards and automotive parts. Rey et al [19] modelled the acoustic behaviuor of recycled polyurethane foam from two different points of view. First, the airflow resistivity was used as a simple parameter to describe the properties of the recycled foam material, on the other hand, the porosity and the average pore diameter of the recycled foam were considered as two simple parameters [19]. Both models provide good predictions of sound absorption of recycled foam. It is noted that these recycled materials have good sound absorption properties and could be a viable alternative to conventional materials for current and future applications.

Among various agricultural wastes, rice straw can be a very interesting material to be used as a filler in biodegradable polymers due to its high thermal stability compared to other agricultural wastes. Rice straw is used for thermal insulation, like fuel, for the production of toothpaste, etc. Rice husk is used as a reinforcement in a composite to improve the sound absorption property of a particular composite [4]. Wang and co-workers incorporated rice husk as a reinforcement in the polyurethane composite. Rice husk improved the physical, mechanical and acoustic properties of the material [20]. This environmentally friendly composite has proven to be an excellent sound absorber in the frequency range below 500 Hz compared to pure polyurethane foam. Thus, the presence of rice husk in this composite shifts its sound frequency response range above 1200 Hz to the lower frequency range. Due to these properties, it finds application in the automotive industry, packaging industry and even in the aircraft industry.

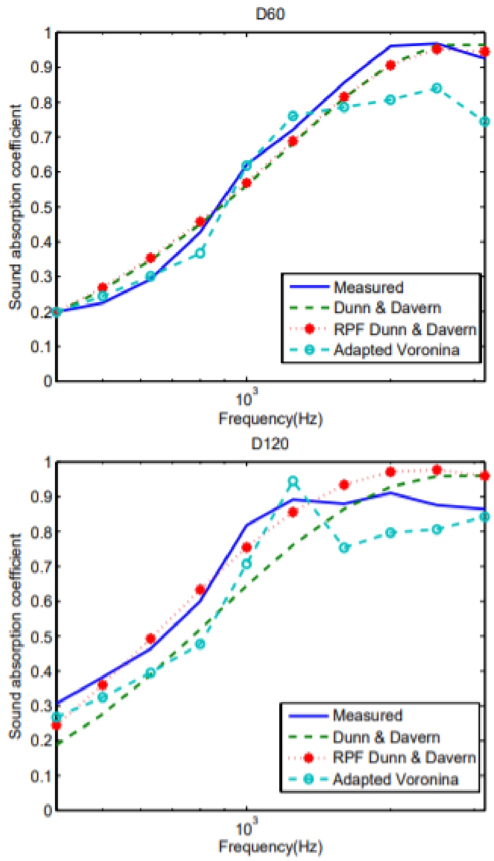

Figure 9: Results of sound absorption coefficient for the different samples of recycled polyurethane foam as a function of frequency [19]

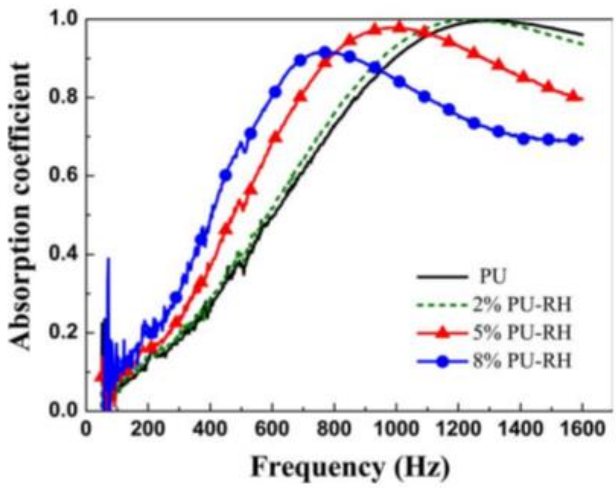

Figure 10: The sound absorption coefficient of various foams [20]

Wood fibre waste such as wood chips is mainly used in the thermoplastic industry. Waste wood is obtained for species of a certain purity and is usually based on certain particle size distributions. The use of composite materials based on textile residues and wood chips to reduce noise has two main advantages, low production costs and low specific weight. Stanciu et al [21] evaluated the acoustic properties of composite structures based on sawdust and textile waste linked by common ecological bonds. Different samples were tested, the differences between samples consist of the quantities of raw materials or the type of binders, which conduct more or less to the compaction of the particles. The composition of the binder has a great influence on the acoustic properties of the sample, ie on the absorption coefficient, the impedance ratio and the reflection coefficient. The absorption coefficient is also affected by the density of the material, increasing the density of the material leads to a decrease in the absorption coefficient [21]. As some of the samples had constant absorption, with high values of absorption coefficients, at different frequencies, it can be concluded that these composites can find application for sound panels for highways, airports and railways.

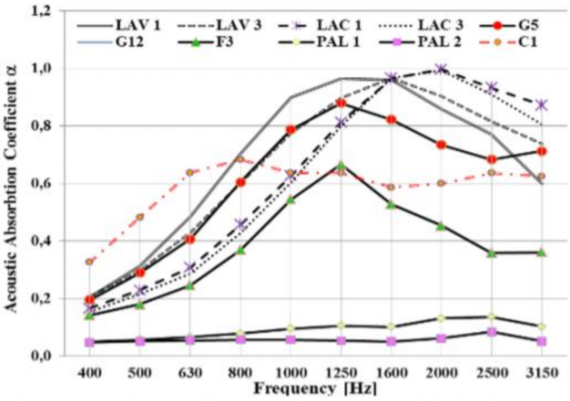

Figure 11: The effect of type of binders on sound absorption coefficient [21]

4. CONCLUSION

The use of composites has developed rapidly in recent years primarily due to the problem of the lack of frequently used sound-absorbing material. This review indicates the importance of research and development undertaken in the field of composite materials that have proven to be good sound absorbers. The three general classifications of this group of materials include composites made from synthetic, natural, and recycled materials.

Materials obtained from synthetic fibre are commonly used for thermal and sound insulation, because of their good performances and low cost. It seems that environmentally friendly, degradable, recycled and green produced noise absorbers will play an important role in the noise absorbers market in the future.

Composites made of natural materials are cost-effective, renewable material, low density, environmentally friendly and reduces CO2 emissions. Natural fibre materials have internal porosity which is suitable for sound absorption, as it provides more airflow resistivity. The performance of natural material in the acoustic field can change by varying its composition, porosity, thickness and other properties.

The research indicated that recycled materials hold promise for use as a raw material for sound-absorbing, being low cost, thanks to the use of wastes derived from other production cycles, lightweight and biodegradability. Recycled materials are becoming an interesting alternative to synthetic materials due to their good acoustic behaviour similar to the traditional porous material. As more research is conducted, and production increases and material-making technology advances, we anticipate that the number of new noise-absorbing materials will increase in the coming years. In this regard, composite materials are particularly suitable because of their ease of manufacture and properties comparable to other materials used for sound absorption

Due to the different application of the absorbent material, researchers should consider the environmental constraints and acoustic characteristics of the sound-absorbing material. Therefore, when choosing sound-absorbing materials, effective noise absorption factors such as fibre size (in fibrous absorbents), air resistance, porosity, placement or position of sound absorbers, compression, thickness and density of absorbents should be taken into account.

ACKNOWLEDGEMENTS

This work is co-financed by the Ministry of Education, Science and Technological Development of the Republic of Serbia on the base of the contract whose record number is 451-03-9/2021-14/200108. The authors thank the Ministry of Education, Science and Technological Development of the Republic of Serbia for supporting this research.

REFERENCES

[1] M. Prašćević, D. Cvetković, "Buka u životnoj sredini", Univerzitet u Nišu, Fakultet zaštite na radu, Vol. 1, (2005)

[2] D. A. Harris, "Noise control manual: Guidelines for Problem-Solving in the Industrial / Commercial Acoustical Environment", Springer Science & Business Media, New York, (1991)

[3] S. Rajappan, P. Bhaskaran and P. Ravindran, "An insight into the composite materials for passive sound absorption", Journal of Applied Sciences, Vol. 17, issue 7, pp. 339-356, (2017)

[4] Md R. Rahman, S. Hamdan, E. Jayamani, M. Khusairy B. Bakri and Md S. Islam, "Biocomposite Materials and Its Applications in Acoustical Comfort and Noise Control", Green Biocomposites, Green Energy and Technology, pp. 247-259, DOI10.1007/978-3-319-49382-4_11,

[5] F. Simancik, J. Jerz, J. Kováčik, P. Minár, "Aluminium foam - A new light-weight structural material", Kovové Materiály/Metallic Materials, Vol. 35, pp. 265-277, (1997),

[6] Fa-Zhi Zhang, T. Kato, M. Fuji, M. Takahashi, "Gelcasting fabrication of porous ceramics using a continuous process", Journal of the European Ceramic Society, Vol. 26, pp. 667–671, (2006),

[7] F. Giese, C. Eigenbrod, and D. Koch, "A Novel Production Method for Porous Sound-Absorbing Ceramic Material for High-Temperature Applications", International Journal of Applied Ceramic Technology, Vol. 8, pp. 646–652 DOI:10.1111/j.1744-7402.2009.02479.x, (2011),

[8] Arenas, J.P. and M.J. Crocker, "Recent trends in porous sound-absorbing materials", J. Sound Vibr., Vol. 44, pp. 12-18, (2010),

[9] W. Dong, T. Faltens, M. Pantell, D. Simon, T. Thompson, and W. Don, “Acoustic Properties of Organic/Inorganic Composite Aerogels”, Materials Research Society Symposium Proceedings, Vol. 1188, Warrendale, PA, (2009),

[10] F. D’Alessandro, G. Pispola, “Sound absorption properties of sustainable fibrous materials in an enhanced reverberation room”, Proc. of Internoise 2005, Rio de Janeiro, Brazil, (2005),

[11] S. Lukić, M. Vojinović, A. Milutinović-Nikolić, “Akustiična svojstva kompozita na bazi konoplje”, Konf za ETRAN, Čačak, (2004),

[12] E. Markiewicz, D. Paukszta and S. Borysiak, “Acoustic and Dielectric Properties of Polypropylene-Lignocellulosic Materials Composites”, In: Polypropylene, Dogan, F. (Ed.). Intech, USA, pp: 193-218, (2012),

[13] W. Yang and Y. Li, “Sound absorption performance of natural fibers and their composites”, Science China Technological Sciences, Vol. 55(8), pp. 2278–2283. doi:10.1007/s11431-012-4943-1 (2012),

[14] H. P. Lee, B. M. Pun Ng, A. V. Rammohan and Le Q. N. Tran, “An Investigation of the Sound Absorption Properties of Flax/Epoxy Composites Compared with Glass/Epoxy Composites”, Journal of Natural Fibers, Vol. 14, pp. 71-77, DOI: 10.1080/15440478.2016.1146643, (2017),

[15] R. Zulkifli, Zulkarnain and M .J. M. Nor, “Noise Control Using Coconut Coir Fiber Sound Absorber with Porous Layer Backing and Perforated Panel”, American Journal of Applied Sciences, Vol. 7, pp. 260-264, ISSN 1546-9239, (2010),

[16] S. Mahzan, A.M. Ahmad Zaidi, N. Arsat, M.N. Yahya, M.N. Mohamed-Hatta, M.I. Ghazali and S.R. Mohideen, “Study on sound absorption properties of coconut coir fibre reinforced composite with added recycle rubber”, Int. J. Integr. Eng., Vol. 2, pp. 29-34, (2010),

[17] Z. Hong, L. Bo, H. Guangsu, H. Jia, “A novel composite sound absorber with recycled rubber particles”, Journal of Sound and Vibration, Vol. 304, pp. 400–406, (2007),

[18] B. Radičević, I. Ristanović, “Koeficijent apsorpcije materijala od recikliranog gumenog otpada”, Zbornik 58. konferencije za elektorniku, telekomunikacije, računarstvo, automatiku i nuklearnu tehniku ETRAN 2014, Vrnjačka Banja, 2-5 juna 2014. godine, ISBN 978-86-80509-70-9, (2014),

[19] Rey, Romina and Fernandez, Jesús and Arenas, Jorge and Sanchis, “Sound absorbing materials made of recycled polyurethane foam”, 40th International Congress and Exposition on Noise Control Engineering 2011, INTER-NOISE 2011, Vol. 3, pp. 2058-2063, (2011),

[20] Y. Wang, C. Zhang, L. Ren, M. Ichchou, M.A. Gall and O. Bareille, “Influences of rice hull in polyurethane foam on its sound absorption characteristics”, Polym. Compos., Vol 34, pp. 1847-1855, (2013),

[21] D. Stanciu, I. Curtu, C. Cosereanu, D. Lica and S. Nastac, “Research regarding acoustical properties of recycled composites”, 8th International DAAAM Baltic Conference "INDUSTRIAL ENGINEERING “, pp. 19-21 April 2012, Tallinn, Estonia, (2012).