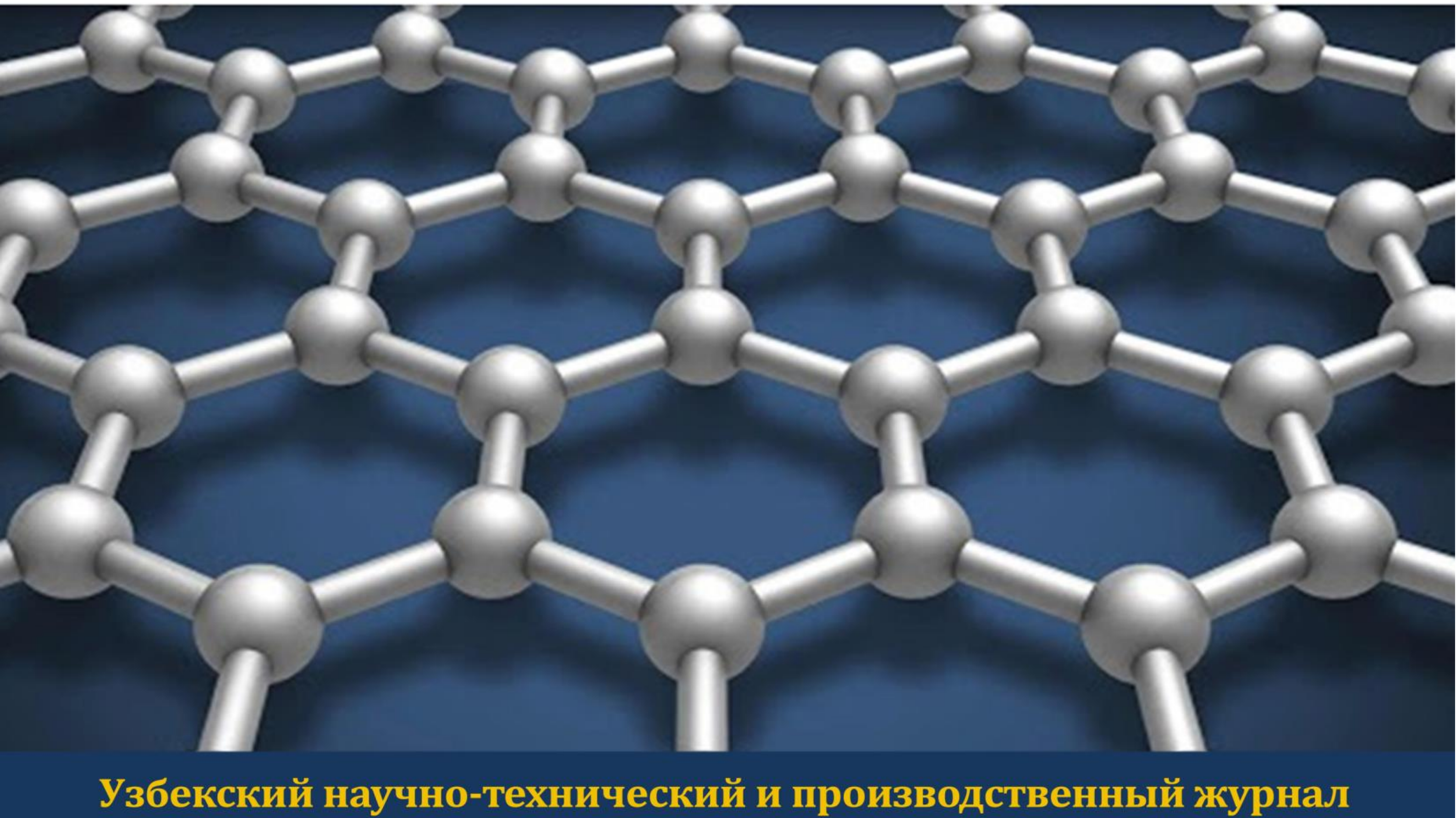
ISSN 2091-5527
№ 3/2024

O'zbekiston

Kompozitsion Materiallar

Ilmiy-texnikaviy va amaliy jurnali



Узбекский научно-технический и производственный журнал

Композиционные материалы

ACOUSTIC ENVIRONMENTALLY FRIENDLY COMPOSITES TO REDUCE NOISE IN PRODUCTION FACILITIES AND TRANSPORTATION

Nodira S. Abed
State Unitary Enterprise "Fan va tarakkiyot"

Acoustic materials are artificial materials designed to dissipate sound energy [1]. There is a distinction between acoustic materials with sound absorbing and sound isolating properties [2, 3]. Generally, sound-absorbing materials have low bulk densities. Their sound-absorbing ability is attributed to their porous structure and the presence of a large number of open communicating pores. Sound-absorbing materials absorb the energy of the sound waves propagating within them. The mechanism of sound absorption is the conversion of sound vibration energy into thermal energy due to viscous friction losses in the pore capillaries or irreversible losses due to the deformation of the fibrous structure of the material (fig.1). The main property of sound-insulating materials is that they reflect sound, thus preventing their passage. As a rule, sound-insulating materials are relatively high density. In a certain sense, acoustic materials also include vibration absorbing and vibration isolating materials [4].

The creation of new noise-reducing materials involves solving interrelated problems in the development of sound-insulating and sound-absorbing materials in a given frequency range. In addition, to reduce the intensity of the transmission of vibrational energy of vibration-active objects from places of origin to places of sound emission, it is necessary to develop appropriate materials with vibration-absorbing and vibration-isolating properties. The overall goal of creating vibration and noise reduction materials is to improve the dynamic mechanical properties associated with the dissipation of wave vibrational energy through viscous friction or irreversible elastic strain losses in the components of the composite material structure.

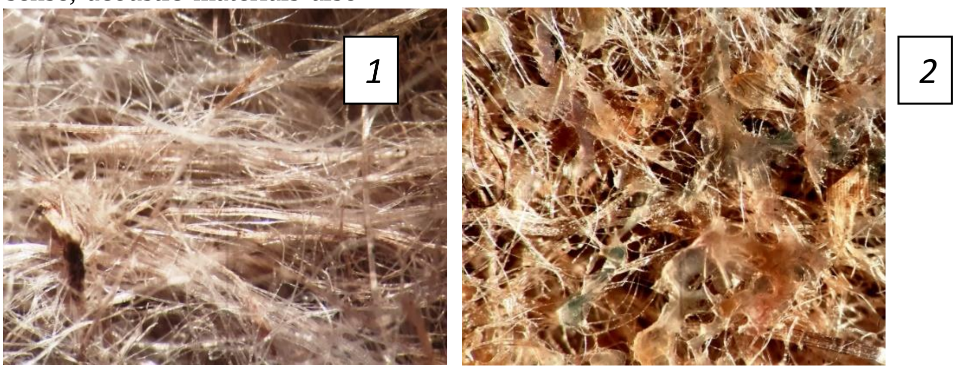


Fig. 1. Microphotographs of a sound-absorbing composite based on flax and polypropylene fibers: 1 – original fibrous canvas (thickness 10-12 mm); 2 – pressed panel (thickness 4-5 mm) [1]

Acoustic biocomposites. Theoretical background and accumulated practical experience, primarily in the automotive industry, indicate that effective innovative materials for vibration and noise reduction can be created based on components (substances) with a high mechanical loss factor over a wide temperature and frequency range. Such substances, as our preliminary studies have shown, include plant fibers and various biodegradable natural linear and branched high-molecular-weight compounds (natural rubber, cellulose, polymerizable resins, starch, and cashew nut shell liquid). It is possible to ensure a high level of acoustic and performance characteristics of composites created on the basis of high-molecular compounds of natural origin and plant fibers (biocomposites) owing to the composition of materials.

Other major advantages of composites based on natural components are relatively low density and, as a consequence, low weight of finished products, ease of utilization, and recyclability. Traditionally used natural components, which are most widely used in the creation of acoustic composites, include flax, hemp, jute, kenaf, coconut fiber, reed, and straw fibers [5-10]. The specific type of natural fiber used depends on both the required physical, mechanical, and acoustic properties of the final products and on the local availability of suitable raw materials.

In several cases, composites based on natural fibers have better physical, mechanical, and acoustic characteristics than composites based on chemically synthesized polymers and fibers. For example, it was shown in [11-14] that the sound absorption properties of composites based on bamboo, kenaf, loofah, date palm, coconut, tea leaf, hemp, and cane fibers are superior to those of similar composites based on polypropylene and polyester fibers. The microstructures of acoustic composites based on flax and polypropylene fibers developed in [21] for noise-reducing interior parts of vehicles are shown in Figure 2.

The analysis of the available literature and our own experience in the use of fibro-granular raw materials of plant origin, as well as biomass as base components for acoustic composites, shows that rice husk [15-17] and buckwheat [18-20] allow the formation of an open porous composite structure with low density and low air flow resistance. These, in turn, are necessary conditions for good sound absorption properties, and fibro-granular raw materials of plant origin as well as biomass can therefore be considered as promising base fillers for the developed sound-absorbing composites.

Innovative meta-, nano- and auxetic materials. In recent years, significant research efforts have been directed towards the development of fundamentally new acoustic composites based on nanotechnology and acoustic metamaterial design principles. In [21], the influence of a layered silicate nanomodifier (montmorillonite) on the dynamic mechanical and acoustic properties of epoxy resin-based nanocomposites used in multilayer noise-suppressing structures was investigated. The addition of 5 wt. % nanomodifier as a functional filler in epoxy resin allows to increase the transmission loss (sound insulation value) up to 58 dB, which is 36 dB more compared to a specimen with the same thickness and basic composition but without modifier. Later, the authors of [22], who investigated the influence of hollow silica nanotubes synthesized by the sol-gel method on the mechanical and acoustic properties of epoxy nanocomposites, came to almost similar results. In [23], the acoustic performance of 1.6 mm thick cellular composites containing fillers (graphene, nanotubes, and polydimethylsiloxane) that enhance the absorption of low-frequency sound waves was investigated.

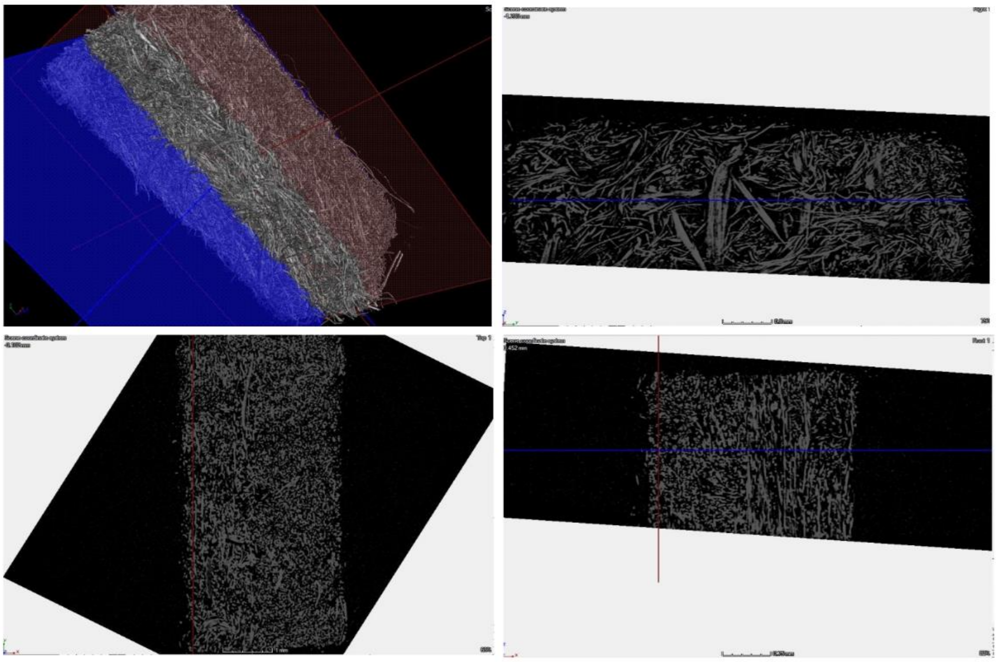


Fig. 2. Images obtained using computer microtomography of sound-absorbing composite based on linen and bicomponent polyester fibers

The maximum sound absorption coefficient values are more than 0.7 at frequencies from 100 to 200 Hz, which significantly exceeds the sound absorption of composites based on widely used carbon foams and microperforated panels. In [24], the acoustic properties of composites modified with nanofibers, nanograin, and nanomembranes were investigated. Composites based on a blend of polyurethane and polymethylmethacrylate forming interpenetrating polymer networks and surfaces modified with nanoclays were proposed. Materials containing nanographite in composites based on piezoceramics and silicone resins are also known. All of these studies note the positive role of introducing nanomodifying fillers as an effective way to improve the acoustic performance of composites, both in terms of sound absorption and sound insulation.

In principle, nanotechnology opens up a large variety of possibilities for creating a wide range of new composites and structures with unique and unconventional properties, including sound insulation and absorption. Although a large body of scientific and technical literature has been published over the past 20 years and there are examples of successful applications of nanotechnology in fields ranging from engineering to medicine, the least significant results in the application of nanotechnology have been achieved namely in the field of acoustic materials.

The current stage of acoustic materials development, thanks mainly to the development and implementation of additive technologies (3D printing methods), is characterized by the emergence of a fundamentally new approach to the formation of artificial metastructures, providing previously unattainable sound absorption characteristics in the mid (250-1000 Hz) and low (below 200 Hz) frequency ranges at relatively small structural thickness. In the available scientific and technical literature, there are examples of sound-absorbing metamaterials realized on the principles of Helmholtz resonators, Fabry-Perot resonators, membrane absorbers, split-tube resonators, metasurface structures, coherent absorbers, acoustic metasurfaces with Frieze symmetries, etc.

The common drawback of all the resonant approaches listed is the narrow range of operating frequencies over which these artificial absorbers are effective. To overcome this drawback, several methods have been proposed, for example, combining elementary cells with different absorption peaks into multilayer acoustic systems, a set of nested microslit absorbers, combining a set of elementary cells with different structural parameters in a single layer, helical spatial resonators with a layer of ultrathin sponge coating, resonators with weak resonance and coherent coupling, nonlocal features, and doubly discontinuous ring resonators. The acoustic metamaterials developed by the authors use the concept of labyrinthine spiral-spatial resonators (Fig. 3), which makes it possible to achieve extremely high values of the sound absorption coefficient (close to 1.0) in the most popular operating frequency range of 500-2000 Hz. The most important advantage of the metamaterials under development is that the proposed solutions make it possible to realize high acoustic efficiency at a previously unattainable ratio of material thickness to the absorbed sound wavelength.

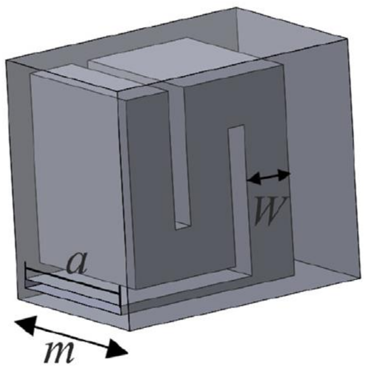


Fig. 3. 3D quarter-wavelength labyrinthine tube of modular acoustic metamaterial (MAMM)

Another type of innovative metamaterials are the so-called *auxetic* materials, which have negative Poisson's ratio and as a result possess exceptional deformation properties, realizing expedient, adaptive responses to service effects (force, temperature, vibration, acoustic, etc.). The distinctive properties of these materials are high volumetric compressibility and shear stiffness, which explain the fact that in auxetic porous materials, the sound absorption coefficient and loss modulus are significantly higher than those of traditional foams at equal values of porosity and density. A comparison of the sound absorption characteristics of porous materials based on traditional polyurethane foam and porous auxetic materials with concave cell shapes shows that the auxetic material has higher sound absorption properties in the low-frequency range up to 1500 Hz; however, at higher frequencies, the sound absorption coefficient of the auxetics does not exceed 0.7.

Thus, based on the analysis of published experimental studies and other available sources, it can be concluded that various combinations of meta-structures, including those possessing auxetic properties, have significant potential for enhancing the sound absorption properties of the developed acoustic composites. It is currently known that there are patented and used solutions from the Rolls-Royce Corporation to improve the acoustic performance of parts of the vehicle interior. At the same time, the complex construction and, in this respect, the low technological performance of the aforementioned meta- and auxetic materials significantly limit their further practical application. Therefore, the creation of high-performance broadband acoustic and metamaterials with a relatively simple structure, meeting the requirements primarily to such parameters as thickness, apparent density, mechanical strength and processability, remains an important unsolved problem and is of interest for further research.

Conclusions. Expanding the range of acoustic (vibration and noise reducing) composite materials remains a topical concern for researchers, primarily at the expense of creating composite materials effective in the low frequency region of the acoustic range; multilayered and with graded density; with an increased temperature operating range in both the low and high temperature region; with improved thermal insulation performance; possessing increased durability, weather resistance and aesthetic performance. The study and systematization of the mechanical and dynamic characteristics of different natural, mainly vegetable fibers, the determination of the adhesion of fibers to different high-molecular-weight matrices, the establishment of the influence of the parameters of the production process on the properties of the product is a very important research task. We therefore propose to investigate, within a unified concept, the properties of natural components contained in plants growing in different climatic regions, taking into account the influence of environmental factors simulating outdoor use conditions. The research results obtained will create good preconditions for expanding the use of plant raw materials, including waste from agricultural and food production, creating biocomposites with special properties which, in aggregate, will significantly increase the role and impact of renewable resources for sustainable materials production and environmental improvement.

Acknowledgments

This research was sponsored by the NATO Science for Peace and Security Programme under grant SPS Project G6006 - "Acoustic Multi-Functional Composites for Environmental Risks and Health Hazards Reduction".

References:

1. Bukharov S. N., Sergienko V. P., Kozhushko V. V., Kudina E. F., Tuleika A. S., Iankov R., Datcheva M., Alexiev A. Acoustic composites and noise-reducing structures. Part I. Environmentally friendly components and nanofillers (a review). Polymer Materials and Technologies, 2021, vol. 7, no. 1, pp. 6–22.

2. Hopkins C. Sound Insulation. Elsevier / Butterworth-Heinemann, 2007. – 622 p.

3. Sound absorbing and sound insulating materials. Ed. By E.Ya.Yudin. Moscow: Stroiizdat, 1966. 248 p.

4. Borisov L.P., Guzhas D.R. Zvukoizolyatsiya v mashinostroyenii [Sound insulation in mechanical engineering]. Moscow: Mashinostroyenie, 1990. 256 p

5. Promper, E. Natural fibre and wood fibre reinforced compounds for automotive interiors – A success story // International congress of raw Material Shift & biomaterials on the 3rd – 4th December 2008.

6. Dirk Frank, e.a. Nonwoven combined material containing bicomponent fibers and method of its production. Patent RF, no. 2147054, 2000.

7. Sergienko V.P., e.a. Sound absorbing composite material. Patent RB, no. 22760, 2019.

8. Verner-Khel'mut Kinkel', e.a. Fibrous material, method for manufacture of fibrous mat, method for manufacture of formed product (versions) and formed products. Patent RF, no. 2074914, 1997.

9. Vudman D.S., e.a. Thermoplastic composite sheets containing natural fibers. Patent RF, no. 2386734, 2010.

10. Anikeenko G.N., e.a. A method of obtaining a tile composite material from lignocellulosic raw materials. Patent RF, no. 2404048, 2010.

11. Koizumi T., Tsujiuchi N., Adachi A. The development of sound absorbing materials using natural bamboo fibers // High Performance Structures and Composites / eds. Brebbia C. A., DeWilde W. P. USA : WIT Press, 2002, pp. 157–166.

12. Chen Y., Sun L. F., Chiparus O., Negulescu I., Yachmenev V., Warnock M. Kenaf/ramie composite for automotive headliner // Journal of Polymers and the Environment, 2005, vol. 13, no. 2, pp. 107–114.

13. Ersoy S., Küçük H. Investigation of industrial tea-leaf-fibre waste material for its sound absorption properties // Applied Acoustics, 2009, vol. 70, is. 1, pp. 215–220.

14. Fouladi M. H., Ayub M., Nor M. J. M. Analysis of coir fiber acoustical characteristics // Applied Acoustics, 2011, vol. 72, is. 1, pp. 35–42.

15. Samaei S.E., Berardi U., Taban E., Parham Soltani P, Mousavi S.M. Natural fibro-granular composite as a novel sustainable sound-absorbing material // Applied Acoustic 181 (2021) 108257.

16. Marques B., Almeida J., Tadeu A., Antonio J, Santos M.I., Brito J, Oliveira M. Rice husk cement-based composites for acoustic barriers and thermal insulating layers // Journal of Building Engineering 39 (2021) 102297.

17. Pachla E.C., Silva D.B., Stein K.J, Marangon E., Chong W. Sustainable application of rice husk and rice straw in cellular concrete composites // Construction and Building Materials 283 (2021) 122770.

18. Sakamoto S., Takauchi Y., Yanagimoto K., Watanabe S. Study of sound absorbing materials of biomass tubule etc. (Measured results for rice straw, rice husks, and buckwheat husks) / Journal of Environment and Engineering. 2011, V.6, No 2, P. 352-364.

19. Kozhushko, V.V. Bukharov S.N., Alexiev A., Iankov R. Buckwheat husk and epoxy resin based composites for noise abating // Journal Akustika. – Vol. 40. – 2021. – P. 17-20.

20. Bukharov S.N., Kozhushko, V.V., Sergienko V.P., Tuleika A. S., Iankov R., Alexiev A., Datcheva M. Sound absorption and sound insulation of acoustic composites based on buckwheat husk and modified epoxy resin // Polymer Materials and Technologies, 2021, vol. 7, no. 4, pp. 33–38.

21. Sergienko, V.P. Development of new environmental safety sound-absorbing materials and layered sound-proofing structures for transport taking into account the spectral characteristics of the noise / V.P. Sergienko, S.N. Bukharov, V.V. Kozhushko, Al. Alexiev, Y. Mirchev, E. Barkanov // Scientific proceedings NTD days. – 2015. – Vol. 150, №1. – P. 469-473.

22. Shi X., Wu J., Wang X., Zhou X., Xie X., Xue Z. Novel sound insulation materials based on epoxy/hollow silica nanotubes composites. Composites Part B: Engineering, 2017, vol. 131, pp. 125-133.

23. Wu Y., Sun X., Wu W., Liu X., Lin X., Shen X., Wang Z., Li R.K.Y., Yang Z., Lau K.T., Kim J.-K. Graphene foam/carbon nanotube/poly(dimethyl siloxane) composites as excellent sound absorber. Composite Part A: Applied Science and Manufacturing, 2017, vol. 102, pp. 391-399.

24. Azarniya A., Eslahi N., Mahmoudi N., Simchi A. Effect of graphene oxide nanosheets on the physico-mechanical properties of chitosan/bacterial cellulose nanofibrous composites. Composites Part A: Applied Science and Manufacturing, 2016, vol. 85, pp. 113-122.