Advanced sound absorbing materials to reduce noise and improve the environmental situation in production facilities and transportation

S. N. Bukharov[1], A. S. Tuleiko[1], V. P. Sergienko[1], S.S. Negmatov[2], T.U. Ulmasov[2], N.S. Abed[2], A.R. Alexiev[3]

[1]State Scientific Institution "V.A. Belyi Metal-Polymer Research Institute of National Academy of Sciences of Belarus", Gomel, Belarus
[2]State Unitary Enterprise "Fan va Tarakkiyot" of Islam Karimov State Tashkent Technical University, Tashkent, Uzbekistan
[3] Institute of Mechanics-BAS, Sofia, Bulgaria

e-mail: sbuharov@tut.by

Abstract. The use of effective sound absorbing materials provides noise reduction and environmental improvement in various spheres of human life, including in residential and production premises, transportation and so on. The trends in the field of creating promising acoustic materials for use in industry and transport are considered. The advantages of using the sound-absorbing composite materials based on linen and polymer fiber and components from them for vehicle cabins are shown. The achieved acoustic and mechanical characteristics of the developed materials allow a reduction of internal noise by 3-5 dBA and meet modern safety and noise requirements.

1. Global noise issue

Environmental noise is one of the urgent global problems [1,2]. Whatever resources are spent by a country or industrial branch on noise abatement, the problem remains to be persistent. Moreover, on the background of the fresh legislative limitations on the noise level, actuality of the problem is only growing. Creation of less noisy machinery could not solve the task since the production is continuously incrementing. As yet, there is neither a globally recognized system of estimates for the environmental noise aftereffects nor any unified normative calculation procedures for evaluating the damage inflicted to the society by noisiness. Nonetheless, the work on elaboration of the general technical, economic and legal approaches to estimating noise effects on the environment and human medium is underway. To name but a few: adopted in 1996 the “Green Book of the European Community” is devoted to the perspective policy in the field of noise. Particularly, it is underlined in the Green Book that above 20% of the world population are subjected to the harmful noise effect and about 170 million of European citizens reside today in the localities experiencing noise attacks in the daytime. The European product certification demands observation of its requirements formulated in the Directive 2000/14/EC and Directive on the transport noise 2000/49/EC that regulate and limit noise emission in the environment. The Directive 2000/14/EC apply to 57 machine types and equipment, including the wheeled and caterpillar transport vehicles, drilling rigs, fridges, compressors, and etc. The Directive 2002/49/EC relating to the assessment and management of environmental noise is the main EU instrument to identify

noise pollution levels and to trigger the necessary action both at Member State and at EU level. The public expenditures on deciding the problems of noise pollution constitute 0.2—2.0% of the GDP, while some companies producing machine parts, e.g., brake systems, spend on the noise abatement item up to 50% of the means allocated for designing. It is evident that the society expends huge sums on the environmental noise problem solving.

In spite of different national programs on shielding noise, unlike prevailing noise sources and technical resources for abating noise pollution, there exist common aspects in the approach to the problems of environmental noise protection.

The methods in this direction include as a rule:

- manufacture of noiseless machinery;
- adoption of technical and town-planning means of protecting human environment;
- planning of urban objects generating noise (express lines, airports, etc.) and domestic building so as to minimize noise effects on the man;
- evaluation of accordance between the noise source (commercial centers, industrial and transport shops, railroads, airports, etc.) and the current Directives and legal acts in this sphere.

The analysis of technical aspects of this problem has shown that the key role in abating environmental noise levels belongs to the design and materials. For instance, in engineering these problems are most often decided by design modification of a unit or machine part, or by applying supplementary noise-abating elements (coatings). To reduce noise of jet engines a noise-absorbing facing is made on the ejector able to alter the phase and amplitude of sonic waves reflected on the turbulent source of the jet stream. Above-stated project envisages solution of the problem of reducing noise levels by creation of the novel materials with the noise-abating properties. Elaboration of such materials consists in deciding several interrelated tasks, namely: development of sound-insulation and sound-absorbing materials that can effectively operate within a wide frequency range, design of structural and triboengineering materials with a low noise emission in the environment. Since noise is generated by oscillating structures in the sonic frequency range, we should add the development of vibration-damping materials to above-named that may increase the oscillating energy losses from the vibrating objects and reduce acoustic transitivity from the place of initiation to the emission sites.

2. Advanced acoustic materials

Despite the variety of formulas and structure, differences in their functional designation (target), sound-abating materials, including vibration-damping ones and the materials possessing low noise emission values, they all pursue a common goal in designing, i.e., amelioration of the properties responsible for dissipation of energy and sonic waves by creating viscous friction in structural elements or irreversible losses at elastic deformation of the material. The theoretical preconditions show that the efficient noise-decreasing materials can be based on the components (substances) having displaying mechanical losses within a high temperature and frequency range. To these belong, first of all, high-molecular compounds (plastic masses, resins, starch, lignin and other). The necessary acoustic properties and performances for specific operation conditions can be attained through choosing the material composition. This means that to create a composite material with noise-abating characteristics and a low vibroacoustic activity, it is expedient to use high-molecular compounds as the matrix phase.

The main tasks in the development of noise-abating materials are to impart ecological safety and minimize harmful effect on the environment at their disposal. For example, noise-abating materials employed in manufacturing interior parts of vehicle cabs makes up in the weight equivalent dozens of thousand tons. Every country encounters the problem of utilizing vehicles by recycling or recovery of the interior materials of cabs and trunks they are made of. Named problems have spurred investigations in suitability of using ecologically safe natural components, including vegetable compounds in composite materials for motor transport. The European motorcar industry is intensively using, for e.g., natural fibers for the noise-absorbing composite materials, and sawdust for the noise barriers. It seems promising to use high-modular basalt fibers, non-spinnable flax fibers, sawdust of various tree species

in designing noise-abating composite materials [3]. As the binders for these composites it is possible to use high-molecular substances like starch, polymerizing oils, lignin and other. To create the efficient vibration-damping composites for the low-frequency range it is proposed to elaborate a technology for reinforcing composites by the hollow glass microspheres or cenospheres. This will make possible to reduce essentially the rate of the longitudinal sound wave propagation in the material and reduce thereby the resonance frequency at which the loss factor is the maximal. The growing use of the natural components in manufacture of composite materials is anticipated in the nearest future. Thus, the use of natural materials is very attractive due to its affordability, low cost and increasing environmental requirements. The dynamic growth with usage of natural components, in the first place, natural fibers, is attributed mainly to the following positive properties:

- Natural materials are ecologically safe and favorable for the environment in any stage of production, usage or recovery;
- Strength characteristics of the composites containing natural fibers may frequently stand on a par with the ones reinforced by chemical fibers;
- The composites with natural fibers are more flexible as compared to carbon or glass fibers, they do not form acute edges at cracking, do not emit toxic or carcinogenic dust;
- The composites with natural fibers are more efficiently suppressing noise and mechanical vibration, which is extremely important for mechanical engineering and construction.

The problem of advanced processing of non-spinnable flax fibers which are inapplicable in fiber-yarn process is very actual for the countries of the European Community, Ukraine and Belarus. According to the data presented by specialists from Lodz University of Technology (R. Kozlowski, M. Mackiewicz-Talarczyk), the areas for flax growing occupy, e.g. in France 67,000 ha, in Belgium and Netherlands 14,500 ha, in Ukraine 12,000 ha, in Belarus 78,500 ha. Subsidy of the European Community on growing and processing flax fiber makes up $800/ha, therefore any losses or low-quality flax fiber production may cause considerable economic damage. So, elimination of the losses by using advanced processing of the flax fiber, e.g., for manufacture of noise-abating composite materials, may raise profitability of flax industry in Europe.

The composites based on flax and polymeric fibers (polyester and polypropylene) are world-wide applied by the leading motorcar manufacturers for vibration- and sound-absorbing parts, luggage compartments, bonnets, cabin interior, and etc. The share of more rigid and foam plastics possessing low noise-abating properties and ecologically unsafe is, however, rather large. The reason is the lack of available assortment of the composites based on natural fibers or ingredients, which impedes their expansion in other applications. One of the aims of the present project is to expand the assortment of the noise-abating composites on the base of vegetative ingredients and natural fibers. This can be attained, first of all, by creation of the composites efficiently operating in the low-frequency sound range, sandwich structures, the objects having gradient density and the ones with improved heatproof parameters, showing elevated strength, wear resistance, along with ameliorated design esthetics. These are new acoustic materials for various purposes.

3. Sound absorbing materials

Sound-absorbing materials are a wide class of artificial materials designed to dissipate the energy of an acoustic wave. In industry, sound-absorbing materials are used for the manufacture of noise-reducing structures and suspended ceilings of buildings, interior panels and facings of the engine compartment of vehicles. In industry, sound-absorbing materials are used for the manufacture of noise-reducing structures and suspended ceilings of buildings, interior panels and facings of the engine compartment of vehicles.

Sound-absorbing materials used in vehicles can be exposed to the most adverse operating factors, including high and alternating temperature and dynamic loads, contact with various aggressive environments (saline solutions, oil products, acids, etc.). Moreover, they must comply with high environmental standards and have certain decorating properties.

The operating conditions and technical parameters of noise-reducing structures in which sound-absorbing materials are installed determine the set of requirements for these materials: the need to ensure a given value of the sound absorption coefficient in a wide frequency range, light weight at specified dimensions, high antibacterial and fire-fighting properties, lack of smell during operation and the release of toxic products during combustion, hypoallergenicity, etc. Sound-absorbing materials must be technologically advanced in production, easily utilized, have an acceptable cost and an affordable raw material base.

One of the requirements for the design of tractor cabs and self-propelled agricultural machines is sufficient visibility, which determines a high degree of glazing of the cab and, therefore, a decrease in the area of sound-absorbing structures [4]. This leads to the fact that the main part of the noise is absorbed by the ceiling elements of the cabin, which in turn leads to the need to increase the sound-absorbing properties of these elements in a wide frequency range. In modern tractors, the ceiling lining is continuous over the entire area of the ceiling. The thickness of the ceiling structure can be significantly increased, which will increase the sound absorption coefficient, especially in the low frequency range. The technology of hot pressing of canvases allows achieving the necessary compaction of the composite material to obtain rigid panels that can perform decorative and frame functions [5].

Modern environmental standards and requirements make us take a fresh look at the materials used, and therefore now a great emphasis is placed on materials that do not require deep processing during disposal. Starting from the 70s of the last century, asbestos-containing fibers are replaced by synthetic, and more recently, compositions of synthetic and natural fibers [6]. Sound absorbing composite materials based on linen and polymer fibers were developed in the works [7]. The main physicomechanical and acoustic characteristics of the materials are shown in table 1 and Figure 1. According to the development results, the production of modern sound-absorbing composite materials and layered noise-reducing structures, as well as thermoformed thermoformed parts (Figure 1) of interior cabins and interiors for vehicles of various types (railway locomotives, tractors, buses, etc.) were launched.

Table 1. The main physical and mechanical characteristics of sound-absorbing materials based on linen and polymer fibers

Parameter	Test method	Parameter value
Thickness, mm	GOST 12023	5.5–10.0
Surface density, kg/m^2	GOST 3811	0.60–1.3
Thermal conductivity, W/mK	STB 1618	0.038–0.041
Breaking load, N:	GOST 15902.3	
by length		117–188
in width		80–123
Unevenness by weight, %, не более	GOST 15902.2	10
Humidity, %	GOST 3816	2
Loss factor (tanδ)	STB 1438	0.110–0.144
Flammability	GOST 30879	Non-flammable
Mushroom resistance, score	GOST 9.0824	1

The achieved physicomechanical and acoustic characteristics of the developed materials meet safety standards for operation (lack of carcinogenic and toxic dust, sharp edges during tearing, bending, cracking, harmful or toxic volatile substances during radiation and convective heating.

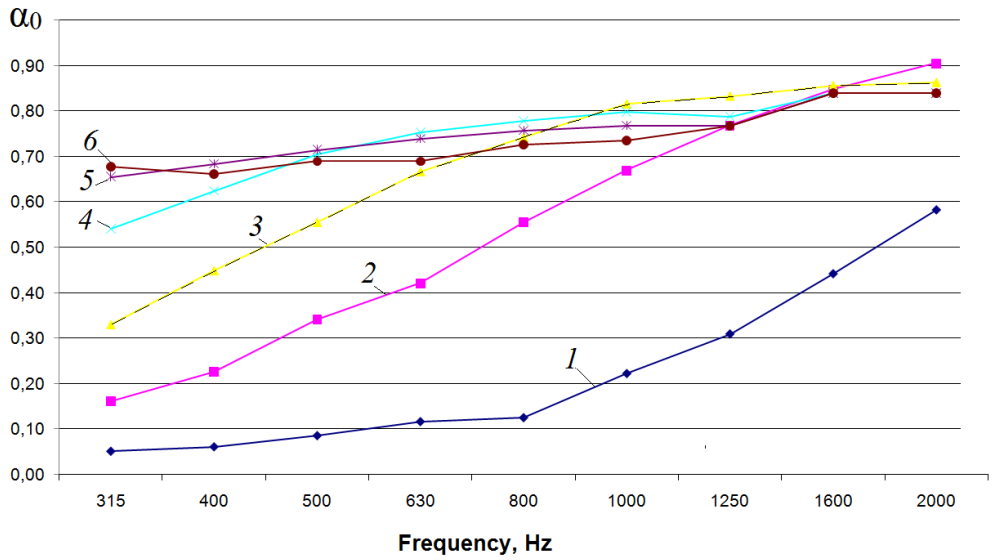

Figure 1. Sound absorption coefficient (α_0) for acoustic materials based on linen and polymer fibers for different thicknesses: 10 mm (*1*); 20 mm (*2*); 30 mm (*3*); 40 mm (*4*); 50 mm (*5*); 60 mm (*6*)

Figure 2. Product examples of interior components made from developed sound-absorbing composites: ceiling elements of the tractor "Belarus" (*a, b*); cover of the inner wheel arches of the tractor "Belarus" (*c*); multilayer noise-reducing structure for the cab of railway locomotives (*d*)

According to the results of acoustic measurements at the tractor driver's workplace, noise levels are reduced by 3-5 dB in the frequency range 500-2000 Hz by replacing the standard interior decoration with noise-reducing parts made of a sound-absorbing composite based on linen and polymer fibers. As shown in Figure 3, noise reduction is implemented in almost the entire frequency range, while due to sound absorption; a decrease in sound pressure levels occurs mainly in the medium and high frequency ranges.

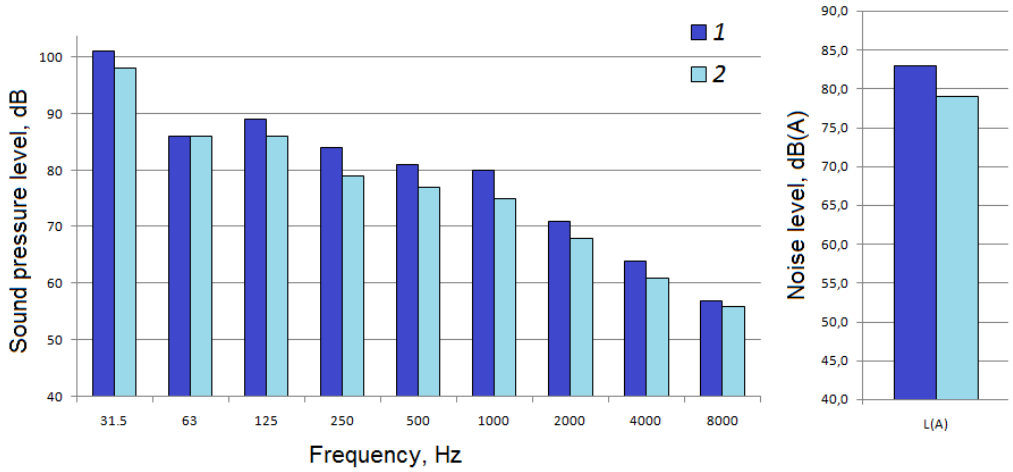

Figure 3. Sound pressure levels in octave frequency bands and sound levels measured when the tractor moves at maximum transport speed with standard interior components (*1*) and interior components made from developed sound-absorbing composites (*2*)

4. Conclusions

The use of natural materials is very attractive due to its affordability, low cost and increasing environmental requirements. Sound-absorbing materials used in vehicles can be exposed to the most adverse operating factors - high and alternating temperature and dynamic loads, contact with various aggressive environments (saline solutions, oil products, acids, etc.). Moreover, they must comply with high environmental standards and have certain decorating properties. In the framework of this work, sound-absorbing composite materials based on linen and polymer fibers and components from them for vehicle cabins were developed. The achieved acoustic and mechanical characteristics of the developed materials allow a reduction of internal noise by 3-5 dBA. The main environmental advantage is the partial biodegradability of the composites through the use of natural components and the transition of the material from bulk monolithic to loose fibrous form, which also greatly simplifies its disposal. The development provides in-depth processing of local raw materials (low-value indirect flax fiber, flax production waste), and the expansion of markets for synthetic fibers.

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