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Development of Gradient Acoustic Composites with Enhanced Sound-insulating and Sound-absorbing Properties

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Abstract
The paper discusses promising way of utilization of the buckwheat husks for production of noise reducing composites for various applications in automotive and buildings industry. Significant amount of produced buckwheat husks allows to suggest it as the environmentally friendly filler for production of polymer based noise reducing composites. A method is proposed for creating a gradient structure of a composite that combines high sound-absorbing and sound-insulating properties in a wide frequency range. The measured normal coefficient of sound absorption is comparable with artificial acoustic materials such as polyurethane foam. At the same time, the measured value of airborne sound insulation is more than 60 dB in the frequency range from 50 to 6400 Hz.

Keywords: sound absorption coefficient, transmission loss, gradient acoustic composites, buckwheat husks

1. Introduction

The high level of noise on the streets of cities and in industrial premises negatively affects a person, namely his health and emotional state, therefore, reducing noise exposure levels is an urgent task to ensure comfortable conditions for the population of cities. The development of measures aimed at reducing the noise safety of residential and industrial premises, as well as reducing sound pressure levels in the transport industry, is an important economic and social task. From the point of view of materials science, intensive work is being carried out to create acoustic composite materials and noise-reducing structures that isolate noise sources and reduce its level in rooms.

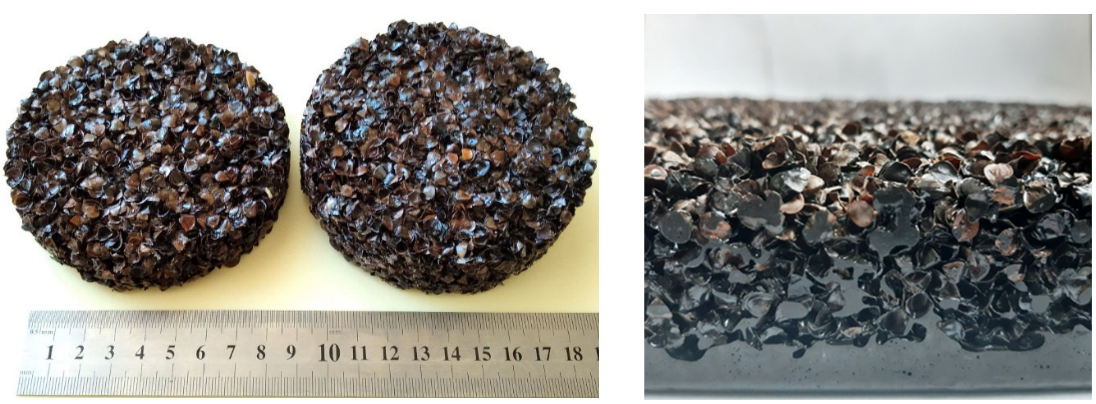
There are no universal materials that are equally well reduce noise at all sound frequencies and at the same time meet all operational requirements. For example, in the vehicle interior some materials have good decorative and protective properties, while others – damping or heat insulation. A large number of factors it must be considered when developing an optimal soundproofing structure. Among them are demands of operational conditions: decorativeness, durability, heat resistance, moisture resistance, biostability, and limitations on thickness, weight and cost.

Development of composite materials is largely determined by environmental regulations and requirements aimed at reducing various harmful for human factors throughout the entire life cycle, including stages of production, operation and disposal of materials. Serious concerns about environmental changes affecting climate are driving researchers to search for fillers and plant-based fibers that rival known synthetic fibers such as mineral and glass fibers in terms of sound absorption, density, and biodegradability. Natural fibers have many advantages compare to synthetic fibers, for instance low weight, low density, low cost, acceptable specific properties and recyclable or biodegradable [1, 2]. Fibers form open pores structure which possess flow air flow resistance while other biomass-derived materials such as rice of buckwheat husks can be used as filler in composite. In addition to fibers, it is possible to use other materials of plant origin: stems and fruit shells.

Buckwheat (Fagopyrum esculentum) is a valuable, widely cultivated cereal crop, the cultivation of which is of great economic importance. Buckwheat is one of the most popular food crops in Belarus and in many other countries of the world. The large-tonnage wastes in the form of straw, husk and bran are produced after processing of buckwheat. The waste amount of buckwheat husk is about 200 kg for each ton of groats [3]. The use of untreated shells as a sound-absorbing material is possible, for example, in the case of floor filling, however, to expand the scope of practical application, molding into slabs with preservation of the porous structure is required. One of the promising solutions is the manufacture of composites based on epoxy resin and its modified variants in order to improve the soundproofing properties of the gradient structure of the composite.

2. Materials and methods

For the manufacture of experimental samples, buckwheat husks were used, provided by the branch of the Gomel bakery plant. The density of the husk kept at room temperature 20±2ºC and humidity 50±10% for 7 days is 145 kg/m^3. Composites are made on the basis of modified epoxy resin ED-20, which was cured using aminoacrylate. Calcium stearate and graphite with a mass fraction of not more than 7% were used as polymer binder modifiers. Epoxy resin provides a sufficiently high rigidity of the composite, is not affected by moisture, does not emit harmful chemical compounds. The proposed technology ensures the production of a gradient composite, the bulk density of which, depending on the thickness, varies in the range 170…700 kg/m^3. For the purpose of subsequent measurements of sound insulation and sound absorption of composites, two molds were made from ABC plastic with an inner diameter of 100 mm and a height of 20 mm and 30 mm. The polymerization of the resin took place at room temperature, the mixture of husks and resin was kept in molds for more than 24 hours, after which the samples were removed and weighed. An image of the samples for acoustic tests is shown in Figure 1(*a*) and composite structure is shown in Fig. 1(*b*).



(a) (b)

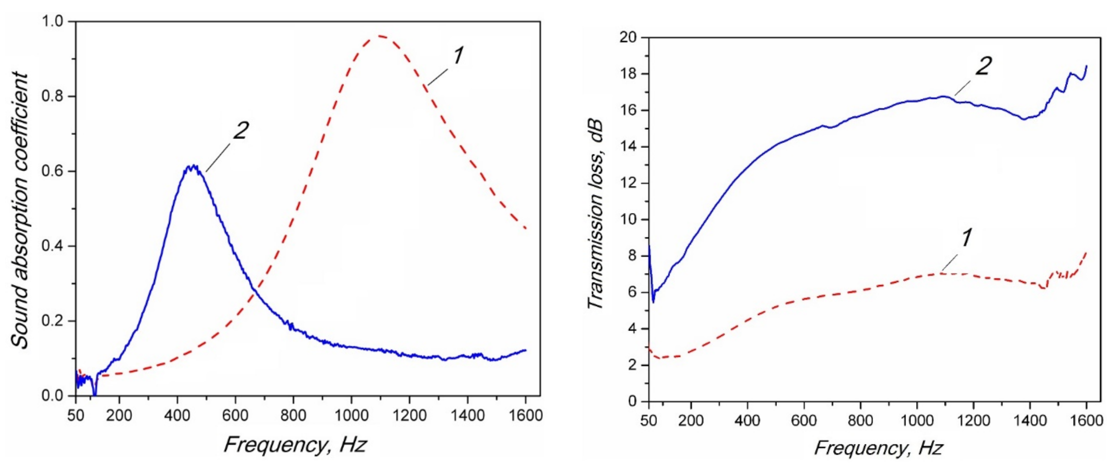
Fig. 1. Samples for acoustic tests (*a*) and gradient structure of the composite based on buckwheat husk and modified epoxy resin (*b*)

Measurements of sound absorption coefficient were performed using the two microphone method (ISO 10534-2:1998) and methodology described in the international standard ISO 13472-2-2010. Absolute values of sound transmission loss were measured for cylindrical samples with a diameter of 100 and 29 mm by four microphone method using the 4206T impedance tubes in accordance with ASTM E2611-17. To determine the spectral characteristics of noise at the source of its occurrence, a system for collecting and analyzing vibroacoustic signals based on a PULSE 3560 analyzer and a 4961 unipolar measuring microphone (Bruel & Kjaer) was used. Brüel & Kjær data acquisition system based on the PULSE 3560B analyzer and a 4961 unipolar measuring microphone (Bruel & Kjaer) was used to determine the spectral characteristics of noise at the source of its occurrence.

3. Results and discussion

The results of measurements of sound absorption and transmission loss of composites based on buckwheat husks and unmodified epoxy resin of various densities are shown in Figure 2. The sound absorption of composites changes significantly from low density composites (500 kg/m3) to denser specimen (700 kg/m3). The 30 mm thick composite has local maximum of absorption at 1100 Hz while the absorption of the denser composite of the same thickness demonstrates local maximum of with the value near 0.6 at the frequencies about 450 Hz. It was above mentioned that the sound absorption is directly related to the porosity since the composites with high porosity (low density) have higher sound absorption in contrast to the materials with low porosity (high density). Thus, the density indirectly determines the efficiency of sound absorption and insulation. The comparison of results related to the sound insulation yields higher transmission loss for denser composite namely above 10 dB for the frequencies >300 Hz while lower density composite approaches only 6 dB in considered frequency range. The sound insulation of porous composite is worse but varying the density and the thickness it is possible to change the position of the local maximum of absorption and transmission loss.

A method for obtaining structure with a smooth change in density along the thickness (density gradient) has been proposed and gradient acoustic composites have been developed that combine high characteristics of sound absorption and sound insulation simultaneously [4].



(*a*) (*b*)

Fig. 2. Results of measurements of sound absorption (*a*) and transmission loss (*b*) of composites based on buckwheat husks and unmodified epoxy resin of various densities: 1 – 500 kg/m^3; 2 – 700 kg/m^3(test specimens of 30 mm thick)

The results of measurements and spectral analysis of noise (Fig. 3), recorded on the territory of the Gomel sorting and dispatch park, showed a significant excess of the maximum permissible sound pressure levels in the entire audible frequency range above 1 kHz. In the normalized frequency range (upper limit is 8 kHz), the maximum permissible levels are exceeded by more than 50 dB.

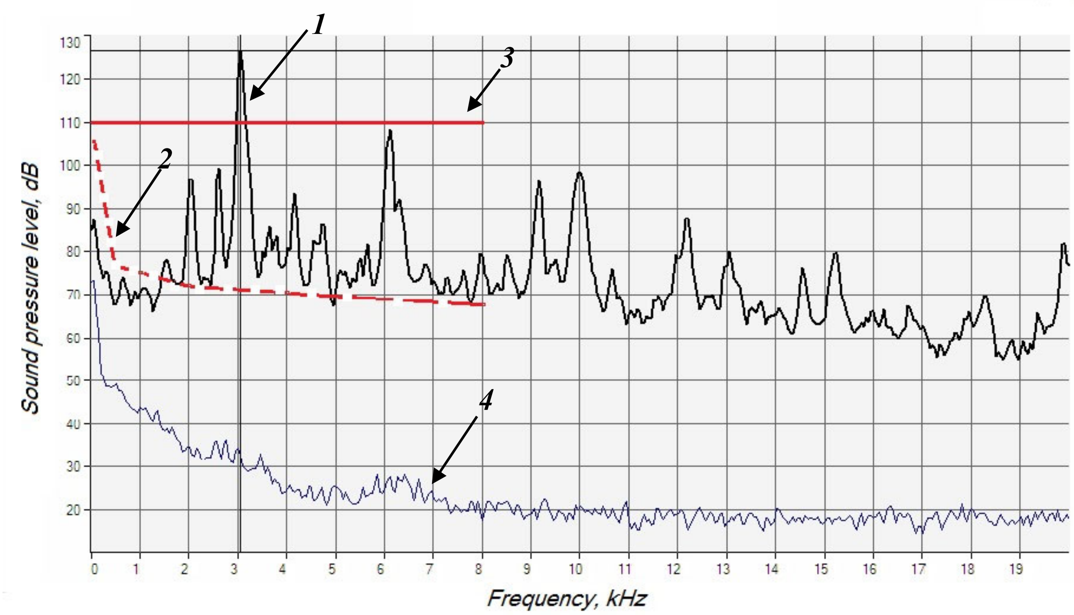


Fig. 3. Results of measurements of the noise generated during braking of railway carriage with standard brakes: *1* – measured noise levels; *2* – maximum permissible levels (MPL) for constant and equivalent intermittent noise; *3* – MPL for the maximum noise value (110 dB); *4* – background noise level

4. Conclusion

Acoustic composites based on buckwheat husk and modified epoxy resins have been developed to solve the problem of reducing noise pollution in nearby residential areas. The structure of the composite has been optimized taking into account the actual spectral characteristics of noise measured during the operation of the brake systems of wagon retarders on railway marshalling yards. A technology for obtaining gradient composites was proposed and a prototype of a noise barrier panel with a normal sound absorption coefficient of 0.6–1.0 and transmission loss of more than 60 dB in the frequency range of 50–6400 Hz was made. According to preliminary estimates [4], the use of such composites in noise barriers can provide noise reduction to the current maximum permissible levels.

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