Green eco-friendly acoustic materials

J Lavrentjev

AcouTech Lab, Department of Mechanical and Industrial Engineering, Tallinn University of Technology, Ehitajate tee 5, 19086 Tallinn ESTONIA

juri.lavrentjev@taltech.ee

Abstract. Green soundproofing acoustic porous materials are a valid alternative to traditional synthetic materials. Green eco-friendly acoustic panels and other soundproofing solutions are made at least in part recycled or natural materials that are safer for the environment. They do not contribute to the environmental and toxic waste problem since at the end of their useful life, green materials can be disposed of without polluting the environment. They are increasingly being used in the automotive industries and also in construction improving the acoustic comfort inside buildings as well as mitigate reverberation effects and reduce the transmission of noise between rooms. In this paper, the acoustic properties of different but typical green acoustic materials are analysed and their acoustic characteristics experimentally determined. The problems of designing of green acoustic materials have been analyzed and the main solutions to the design and use in acoustics have been proposed. The effect of the structure and arrangement of materials on the acoustic properties of materials has been analyzed.

1. Introduction

The green eco-friendly acoustic materials are usually defined as acoustical sustainable materials, either natural or made from recycled materials. They are more and more a valid alternative to traditional synthetic materials. People recognise more that both construction of new homes and living in a home can create a big carbon footprint, and people are looking for green-built homes to reduce that footprint. The production and using of these materials generally has a much lower environmental impact, but a proper analysis of their sustainability, through Life Cycle Assessment has to be assessed. In fact many natural materials (bamboo, straws, wood industry waste of different fractions) show good sound absorbing performances [1]. Not all currently used recycled acoustic materials can be considered sustainable in terms of the energy consumption and impact to the human health. For instance, mineral wools are widely used for thermal and sound insulation, because of their good performance and low cost. However, mineral wool fibres, can cause skin irritation and dangerous when inhaled. [2, 3]. In the last years a great attention has been focused on green eco-friendly materials and many research centres have developed new sustainable materials, in many cases with interesting acoustical properties [4, 5]. However, many materials do not reach their potential acoustic properties, mainly due to the lack of general design principles. The aim of this work is to summarize the main failures in the design of these materials, based on the experience gained from the research of these materials in the AcouTech Lab of Tallinn University of Technology.

2. Experimental investigation

The most common parameter to characterize acoustic properties of materials is the absorption coefficient. There are two techniques to experimentally determine the absorption coefficient: the
The reverberant room method usually following ISO 354:2003 [6] and the impedance tube transfer function method which follows ISO 10534-2:1998 [7]. In the first case (see Figure 1a) the absorption coefficient is determined in random incident sound field conditions inside a test chamber while in the impedance tube (see Figure 1b) only a direct incident field is considered. The results obtained from these two methods are identical only if the acoustic material is acoustically isotropic which condition is not satisfied in the case of porous acoustic materials.

![Figure 1. The techniques to experimentally determine the absorption coefficient, a) the reverberant room method, b) the impedance tube method.](image)

The main advantage of the impedance duct method is the requirement of only a small test specimen size, equal to the tube cross-section area, usually few square centimeters. The measurable frequency range is determined by the inner diameter of the tube, setting the upper limit by the cut-off frequency of the higher-order modes. Typical measurement frequency range for impedance tube method is 100-8000 Hz. The standard reverberation room method demanding a minimum specimen size of 10m². The method is suitable for a frequency range from 100 to 5000 Hz. In this paper the absorption coefficient of the acoustic materials is determined in reverberation room and in some cases the results obtained from impedance tube method for comparison are presented.

2.1. Reverberation room method
In reverberation room method the averaged reverberation time is measured inside the room with and without the test specimen fitted into: determining $T_1$ and $T_2$ accordingly. From the difference between the reverberation times an equivalent sound absorption area of the test specimen is calculated and the sound absorption coefficient is obtained by dividing the equivalent sound absorption area by the absorbing area $S$ of the test specimen. The experimental investigation was carried out at Tallinn University of Technology, in AcouTech Lab [8, 9], see Figure 2. The reverberation room has volume of 66 m³ which is less than specified in standard but it allows to use 2.5 m² specimens for absorption coefficient determination. The tests were performed by applying the interrupted noise technique, with pink noise emitted from an omnidirectional loudspeaker Brüel & Kjær 4292-L driven by an amplifier Brüel & Kjær 2734. The additional equipment used for this test includes the following: 2-channel noise level meter Brüel & Kjær 2270, condenser microphones Brüel & Kjær 4189, scanning microphone boom Brüel & Kjær 3923, a calibrator Brüel & Kjær 4231.

3. The measurement results
First typical acoustic material and the experimentally determined absorption coefficient is presented in Figure 3. It is a natural material made from leather waste. It is light and soft reticulated foam with open porosity about 90%. Due to technological restrictions it can be produced only in 10 mm thickness.
First it is seen, that due to anisotropic material, the absorption coefficient is different weather measured in random incident sound field or direct incident sound field. Generally it is true that in random incident field the porous acoustic material exhibits larger sound absorption coefficient, since for the sound front coming oblique to the material surface. It is also clear that the small thickness of the material only has reasonable absorption coefficient only from 1000 Hz and above, which is not satisfactory for most of the applications. The maximum value reaches value 1, which shows that the porosity is good and has open pore system. Using the same material, experiments were performed with multiply layers of the material. In order to save material, the experiments were done in impedance tube. Then only small multiple specimens were needed, see Figure 4. It can be seen from the results, that with the adding layers, the impedance improves at the lower frequencies and retain the value at middle and higher frequencies. The four-layer case (40 mm thickness) is comparable with the industrial glass-fibre material covered with perforated textile (42 mm thickness). So the thickness matters and the technology should support production of thicker materials.

Figure 5 shows the measurement results for solid plate, having sub-millimeter size holes forming perforation. Typically these plates have thickness of 0.5 to 2 mm and becoming popular in different applications [10, 11]. In order to achieve reasonable absorption coefficient they are placed at the distance from solid surface. As it is seen from Figure 5, the increasing distance shifts the maximum values to the lower frequency region.
Figure 4. Reticulated leather waste foam, measured in impedance tube. Blue solid line – one layer, red dashed line – two layers, brown dotted line – three layers, green dashed-dotted line – four layers. Black long dashed line – reference material.

Figure 6 shows the result of thin carpet with the thickness 5 mm. Due to soft structure it cannot be placed at the distance from solid surface. Small thickness causes low absorption coefficient at low and middle frequency range. Due to big pores it has average absorption at higher frequencies. Figure 7 shows the results for panels made from wool residues. The panels have formed shape after applying pressure. The solid shape keeps the panel material at the certain distance from solid surface. As a result the absorption exhibits good values already at the low and middle frequency range. The maximum value however reaches only value 0.8. It is caused by the bad pore structure typical to fibre type porous materials. The measurement result for wheat straw pressurized panels (thickness 28 mm) are shown in Figure 8. Low values of the absorption coefficient are mostly caused by the big and partly closed pores of the straws.

Figure 5. Microperforated plate, made from recycled metal. Placed at 25 mm and 50 mm from solid surface.
Figure 6. Thin (5mm) carpet made from recycled plastics

Figure 7. Panels made from wool industry residues. Thickness 5 mm, pressurized together and rigid.

Figure 8. Wheat straw pressurized panels, thickness 28 mm.
Conclusions
In this paper the acoustic properties for green recycled and natural materials are investigated. The absorption coefficient is determined for different type of materials and their combinations. The absorption coefficient has been measured by implementing two standard techniques in comparison: the impedance tube method and the reverberation room method. Generally it has been demonstrated that an eco-friendly and recyclable novel porous material can offer an affordable replacement for synthetic foams and fibrous materials if the right design principles are applied.

The general design principles of green acoustic materials in order to achieve noise attenuation potential can be listed as follows:

- the best results exhibit porous materials with open pore structure, the pores should have small size
- the core material should have high elasticity
- the thickness of the material should be large enough to offer reasonable attenuation at lower frequencies
- in the case of thin material it should be placed at least one quarter of sound wave wavelength of the frequency range interested

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