International Journal of Engineering Research And Management (IJERM)
ISSN : 2349- 2058, Volume-03, Issue-06, June 2016

Composite from Raw Renewable Materials with Sound Absorbing Properties

Agnese Nagle, Edgars Kirilovs

***Abstract* — Noise reduction is a significant component in creating a professional and suitable work environment as open-plan offices have become a quintessential trend of the 21st century. The most common solutions in noise control include installation of noise absorption barriers and acoustic systems. Bio-based materials show good sound absorption performances, at the same time leaving much lower environmental impact than traditionally used synthetic materials.**

Research is focused on designating the optimal structure of composite materials in order to obtain a material with high textural qualities of the surface and a noise absorption level that reaches an average noise absorption coefficient value of α_w = 0,5 in at least one set of specified frequencies. Following variables were analyzed in the research: the proportion rate of wool and wood shaving fibers, the panel layer thickness within 15cm - 25cm range, the number of layers per sample material. For measuring the acoustic properties of the sample materials an impedance tube was used. The measurements were carried out in 8 different sample categories, total of 40 samples were prepared and tested.

The main objective in creating the material was for it to absorb high frequency noises and have physical properties for easy adaption in open-planed public spaces.

***Index Terms*— proliferous noise absorbing materials, renewable biological composite materials, noise reduction coefficient**

I. Introduction

The modern office culture introduces open-plan work spaces as the new normal. Employees are constantly surrounded by noise, often causing lack of privacy, inability to focus and additional stress. Acoustic problems can be solved by installing sound absorption panels or using space dividers or furniture with specific sound absorbent finishing. [1] Market supply is saturated with wide variety of acoustic and sound absorption materials, however large portion of these materials are highly time consuming to manufacture and need to be in specific combinations with others to use.
The main focus of the research is to develop a structurally resistant composite material providing a sufficient noise absorption and meeting legal requirements for applicable office environment. The best targeted outcome would be achieving one peace "ready to use" material that does not require any post-processing actions, other than cutting by size and shape.

Manuscript received June 22, 2016

Agnese Nagle, Institute of Design Tehnologies, Riga Technical University, Riga, Latvia.

Edgars Kirilovs, Institute of Design Tehnologies, Riga Technical University, Riga, Latvia.

Composite is made of core elements - discarded wood shavings and sheep wool compounded with adhesive material - vegetable oil based bio-resin.

II. Materials

For the production of composite material has chosen three different components. Main criteria in choosing the specific raw materials are following:

- Functional concordance;
- Impact on the environment (extraction, manufacturing, use);
- Local availability.

Wool is a natural fiber composed of proteins, as it comes from the fleece of sheep. The wool fibers have crimps or curls, which create pockets filled with air. The outside surface of the fiber consists of a series of serrated scales, wool fibers have a unique surface structure of overlapping scales called cuticle cells. The sheep wool is an excellent sound absorbing material, due to micro cavities of which it is compose. When the sound wave is incident on the fibers, the viscous effect between fiber frame and numerous air cavities attenuate part of sound energy and convert it into heat. [2]

For product prototype was used discarded wool fiber from Latvian blackhead sheep wool.

Bio-derived epoxy systems is enabling companies to create environmentally friendly, high performance composite products. [3] Bio-resin is a resin system based on vegetal oil and/or other natural ingredients. The hardener, (the integral part of the resin system), generally contains blocked isocyanate, with the intention to achieve its role and in the same time preventing the escape of the potential harmful substance. In this way bio-resin offers a work environment toxicologically free being kindly with the atmosphere. [4]

For the material prototype used bio – based epoxy resin system SuperSap 100/1000. The system was supplied by Ferrer Dalmau, Barcelona, Spain. As opposed to traditional epoxies that are composed primarily of petroleum based materials, SuperSap formulations contain up to 37% of bio-based renewable materials sourced as co-products or from waste streams of other industrial processes, such as wood pulp and bio-fuels production. [5]

III. Methods for Production of Samples

The composite samples, with wool fiber and wood shavings were made by combining hand lay-up and press molding. Samples were made at ambient temperature, without fiber treatment. Wool and shavings was mixed with binder separately.

Samples created in dimensions 100 mm × 100 mm, with two different thickness – 15 mm and 25 mm.

The samples were compacted by could press mold with thickness regulation, as shown in figure 1. The method is similar to hand layup technique, with the exception that makes use of a matched dies which are closed before cure takes place by the application of pressure.

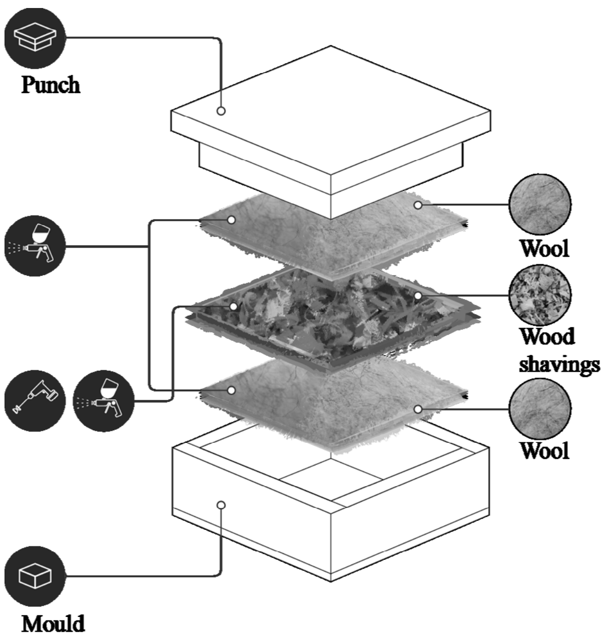

Figure 1. Preparation of the sample – schematic drawing

Wood shavings mixed with binder by using spray gun to add binder gradually and electronic construction mixer, to mix the components evenly. The wool fiber covered with binder by using spray gun.

Samples made according to the experimental design matrix (Table 1). Where varied sizes such as x1 - material sample thickness mm x2 - wool and wood particle mass ratio% and x3 - number of layers. Fixed factors: sheep wool and wood shaving total weight - 40g, binder content, relative to the mass of filler, wood shaving – 6%, wool – 16%.
For sample with 10% wool content 4g wool and 36g wood shavings has used. For sample with 20% wool, 8g wool and 32g wood shavings has used.

Table 1. Experimental design matrix

Sample	Experimental matrix			Work matrix		
	x1	x2	x3	z1	z2	z3
W10-2-15	1	1	1	15	10/90	2
W10-3-15	1	1	-1	15	10/90	3
W20-2-15	1	-1	1	15	20/80	2
W20-3-15	1	-1	-1	15	20/80	3
W10-2-25	-1	1	1	25	10/90	2
W10-3-25	-1	1	-1	25	10/90	3
W20-2-25	-1	-1	1	25	20/80	2
W20-3-25	-1	-1	-1	25	20/80	3

IV. Physical Properties

Density

Maintaining a constant material weight, samples with two different densities were created. The density for 15 mm thick material is 266,66 kg/m³, for 25 mm thick material density is 160,00 kg/m³.

Wool fiber structure

To analyze wool fiber material structure, wool fiber was scanned with electron microscope (SEM) in 2500x increase. Figure 2 shows untreated wool fiber and with resin treated fiber.

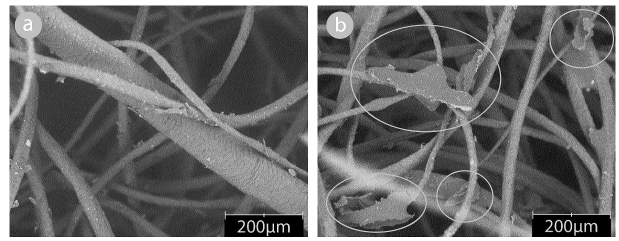

Figure 2. a – untreated wool fiber, b – with bio – resin treated wool fiber

As shown in figure 2, structure of untreated wool fiber is friable, with bio – resin treated wool fiber structure is denser. Figure 2b shows that bio – resins are concentrated in small amount evenly around wool fibers, and does not effect wool fiber properties.

V. Sample Testing

All samples with different percentages of wool and wood shaving proportion have been tested for sound absorption coefficient and thermal conductivity.

Sound absorption coefficient

Sound absorption coefficient (α) was measured according to ISO 10534-1:2002 standard - Acoustics - Determination of sound absorption coefficient and impedance in impedances tubes - Part 1: Method using standing wave ratio. This method is used to determine the sound absorption capacity of a material in response to the normal incidence sound wave. [6]

Test was carried by using an impedance tube, two microphones and a digital frequency analyzer (Fig. 3). The sound absorption coefficient was measured using two microphone impedance tube AFD 1000 – Acoustic Tube by the company Akustik Forschung. [7]

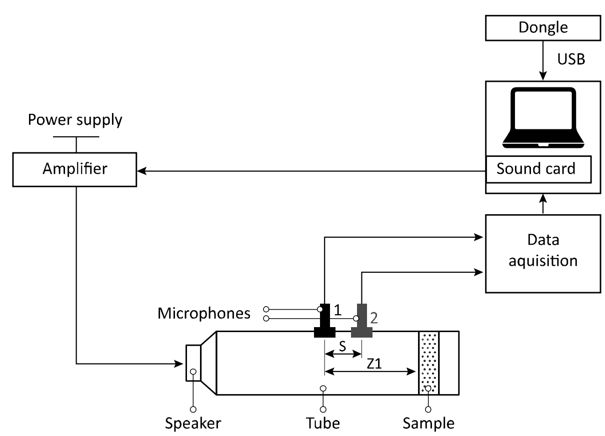

Figure 3. Two-microphone impedance tube

- The diameter of the tube – 40 mm;
- The distance between the two microphones used:

s = 35 mm;

- The distance between the sample and the microphone: z1 = 115 mm.

Test was made for 8 sample groups – 40 samples.

Thermal conductivity

Thermal conductivity was measured according to ISO 8301:2001standard - Thermal insulation - Determination of steady-state thermal resistance and related properties - Guarded hot plate apparatus.

Thermal conductivity of samples was determined using the thermal conductivity measuring equipment FOX600 by the company Lasercomp.

VI. Results

Sound absorption coefficient

Figure 1 and 2 demonstrate the results for samples with 10/90 and 20/80 wool / wood shaving proportion.

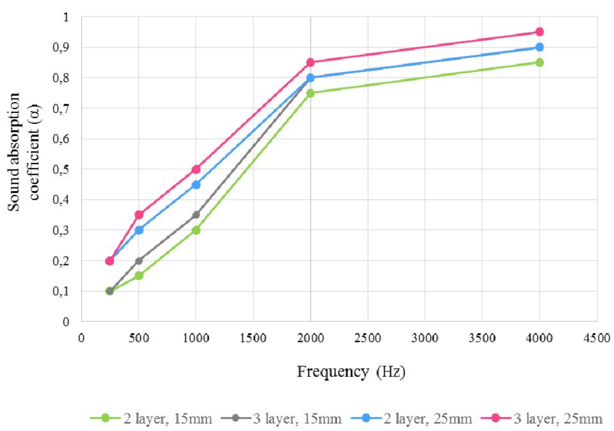

Figure 4. Sound absorption coefficient in frequency range from 250Hz to 4000Hz. Wool / wood chips proportion 10/90

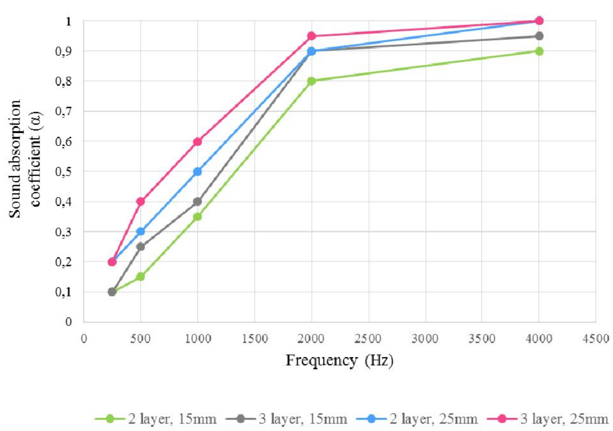

Figure 5. Sound absorption coefficient in frequency range from 250Hz to 4000Hz. Wool / wood chips proportion 20/80

The measured values of sound absorption coefficient for all tested material type samples is high at high frequency range (1000 – 4000Hz). At medium and low frequency values, the absorption coefficient assumed low values (Fig. 4, 5).

At high frequency range from 2000Hz to 4000Hz observed minimal sound absorption coefficient increase. In low and medium frequency range (250Hz – 1000Hz) observed a gradual increase in sound absorption coefficient.

Maximum values in all cases reached at 4000Hz, where the individual variations of sound absorption coefficient α = 0.85 to 1.

For materials with smaller volume density sound absorption coefficient is higher. For thinner materials sound absorption ratio values are smaller at low frequency range.

Noise Reduction Coefficient

Further analysis has been made by calculating the Noise Reduction Coefficient (NRC) values. Theoretically, it was calculated as average arithmetic value of sound absorption coefficients at four frequencies of 250, 500, 1000 and 2000 Hz indicating a material's ability to absorb sound.[8] Table 2 shows the results of NRC values obtained for all samples.

Table 2. Noise reduction coefficient for various samples

Thickness (mm)	Wool / wood shavings (%)	Number of layers (pc)	NRC (α_w)
15	10⁄90	2	0,33
	10⁄90	3	0,36
	20⁄80	2	0,35
	20⁄80	3	0,41
25	10⁄90	2	0,44
	10⁄90	3	0,48
	20⁄80	2	0,48
	20⁄80	3	0,54

By analyzing the structural characteristics of the material impact on the sound absorption properties of the calculated values of the NRC, the full first-degree factor experiment results displayed graphically, and in form of mathematical model - part of the second degree polynomial form, which describes the average sound absorption coefficient α_w value depending in the material thickness (mm), wool and wood shaving proportion (%) and number of layers in material structure.

The most significant sound absorption coefficient impact factors are thickness of sample and sample structure – the number of layers.

$$Y_{L1} = 0,444 - 0,064 * x1 - 0,029 * x3 - 0,001 * x1 * x3 \quad (1)$$

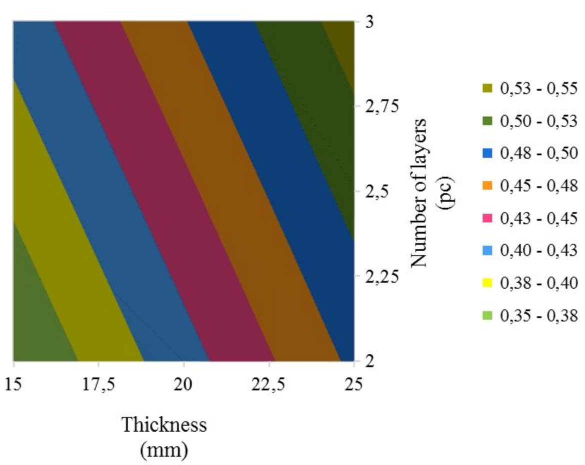

Figure 6. Sound absorption coefficient

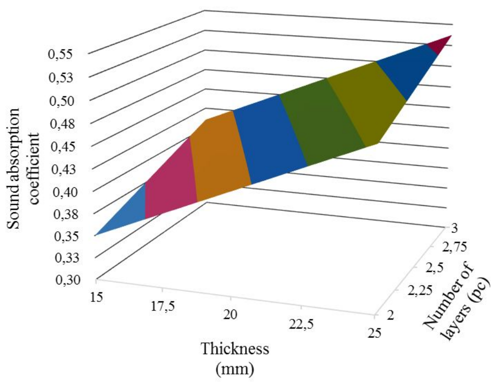

Figure 7. Sound absorption coefficient

According to the mathematical model Y_{L1} and the echo surface (Fig. 6, 7), it can been seen, that the materials with three-layer structure presented higher average sound absorption coefficient values than materials with a two-layer structure. According to the mathematical model coefficients, the proportion of components (wool and wood shavings) effects the sound absorption least.

Maximum efficiency is achieved at 3-layer combination structure and 25mm thickness.

Thermal conductivity

The thermal conductivities of tested samples are shown in Table 3.

Table 3. Thermal conductivity

Sample	Thickness (mm)	Wool / wood shavings (%)	Number of layers (gb)	Thermal conductivity (W/mK)
V20-2-25	25,05	20/80	2	0,036
V20-3-25	25,06	20/80	3	0,032
V10-3-25	25,06	10⁄90	3	0,035

The thermal conductivity of the composite board samples changed within the range from 0.032to 0.036 *W/mK*. The smallest thermal conductivity is for 25 mm thick sample, whit 3 layer structure and 20% content of sheep wool.

VII. Material Use

Experimental material can be used as sound absorbent in interior, to control acoustical qualities in open plan spaces. Material with two layer structure can be used as decorative ceiling and wall panels and tiles (Fig. 8). Material with three layer structure can be used as panel element in space divider systems (Fig. 9).

VIII. Conclusion

Measurements of sound absorption coefficient according to LVS EN ISO 10534-1:2002 standard were performed using a full resistance impedance tube. The measurements were carried out in 8 different sample categories, 5 samples per each category were prepared and tested.

As detected, the structural composition - the number and thickness of layers of the material has a significant impact on it's noise absorption qualities at the lower frequency range from 200 Hz to 500 Hz. Respectively increasing the thickness or/and count of composite layers improves the sound absorption level. However at the high frequency range from 500 Hz to 4000 Hz the proportion of composite materials has primal impact on the sound absorption qualities and increasing the amount of wool fibers corresponds to higher sound absorption levels.

100% of tested samples show the best sound absorption qualities in the high frequency range from 500 Hz to 4000 Hz

At low range frequencies from 250 Hz to 500 Hz. The sound absorption qualities of test samples increase as the thickness of the material and number of composite layers is increased.

As the proportion of wool fibers in the test samples is increased, the sound absorption level in frequency range from 500 Hz increases.

References

[1] Smith, M., M. *Hearing History: A Reader.* Athens and London: University of Georgia Press, 2004. 448 pp. ISBN-10: 0820325821

[2] *Mishra, S. P.,* A Text Book of Fibre Science and Technology. *New Age International Publishers, 2000. 363 pp. ISBN 8122412505*

[3] *Mohanty, A., Misra, M., Drzal, L.,* Natural Fibers Biopolymers and Biocomposites. *1 edition. Boston: CRC Press, 2005. 896pp. ISBN 9780849317415*

[4] Rongpeng, Wang. *Manufacturing of vegetable oils based epoxy and composites for structural applications*. Doctoral Dissertations. Missouri: Missouri University of Science and Technologies, 2015. Paper 2329

[5] Entropy Resins, Super Sap One 100/1000 Data Sheet. [online]. US. [viewed: 10 January 2016]. Available from: https://entropyresins.com/wp-content/uploads/2014/03/TDS_ONE_v1.pdf

[6] Metha, M., Johnson, J., Rocafort, J. Architectural Acoustics. USA: 1999. 446 pp. ISBN 0137937954

[7] Akustik Forschung, Analysis Software AFD 1001 - Measurement of Sound Absorption Coefficient acc. to DIN EN ISO 10534-2. [online]. Germany. [viewed: 29 May 2016]. Available from: http://www.soundbook.de/download/AFD1201.PDF

[8] Metha, M., Johnson, J., Rocafort, J. Architectural Acoustics. USA: 1999. 446 pp. ISBN 0137937954

Agnese Nagle Mg.sc.ing., Riga Technical University, Faculty of Materials Science and Applied Chemistry, Institute of Design Technologies.
Work experience: interior and product design.
Address: Institute of Design Technologies, Riga Technical University, Kipsalas Str. 6, Riga, LV-1048, Latvia.
E-mail: agnese.nagle@gmail.com

Edgars Kirilovs Dr.sc.ing., doc., Riga Technical University, Faculty of Materials Science and Applied Chemistry, Institute of Design Technologies.
Main fields of research are: the use of innovative boards in the production of wooden products and wood product design adjustment to the options of modern technologies
Address: Institute of Design Technologies, Riga Technical University, Kipsalas Str. 6, Riga, LV-1048, Latvia.
E-mail: edgars.kirilovs@rtu.lv