Environmental and Climate Technologies
2020, vol. 24, no. 3, pp. 364–372
https://doi.org/10.2478/rtuect-2020-0109
https://content.sciendo.com

Method to Recycle Paper Sludge Waste: Production of Panels for Sound Absorption Applications

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***Abstract* – Paper sludge is the water treatment waste, which produced during paper production. Paper sludge (PS) waste utilization is the common problem in the EU and internationally. According to the waste management directive No. 2008/98/EC, paper sludge waste should not be utilized in landfills. In the European Union, alone 93 million tons of PS generated yearly. Nowadays most of the paper sludge waste used as fuel for incineration power plants (up to 55 %). According to waste management legislation such waste management should be avoided as well. Very small portion (10 %) of PS is used in construction sector. In construction, paper sludge used as additive in concrete composite materials. Such legislation of waste management generates the motivation of this study. In this study authors propose to produce composite panels in which PS is the main material of composite. As the binding material, clay proposed due to its good binding properties and therefore its natural material. Such produced panels proposed to use it for sound absorption applications. To determine composites sound absorption coefficient standard ISO 10534-2 method was used. The sound absorption coefficient in different octave bands reached up to 0.59.**

***Keywords* – CLAY; composite materials; paper sludge; recycling; sound absorption**

Nomenclature		
H_{12}	Transfer function between microphone	–
p_1, p_2	Pressure in microphones 1 and 2	Pa
S	Distance between microphones	mm
X_1	Distance between microphone No. 1 and sample	mm
X_2	Distance between microphone No. 2 and sample	mm
H_I	Transfer function for incident wave alone	–
H_R	Transfer function for reflected wave alone	–
k_0	Wave number	m^{-1}
R	Sound reflection coefficient	–
α	Sound absorption coefficient	–

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1. Introduction

Noise in general becomes more and more discussed topic in the public. According to the EU statistics about 40 % of population is exposed to road, air or rail traffic and noise levels exceed 55 dB(A) [1]. The most those people are exposed to the traffic noise [2]. One of the solutions to reduce the noise levels is to use sound absorbing materials.

Paper sludge is the water treatment waste, which produced during paper production. Paper sludge (PS) waste utilization is the common problem in the EU and internationally [3]. According to authors Frias *et al*. paper sludge is the main waste in the paper processing factories, the percentage reach 35 % of product volume [4]. According to the waste management directive No. 2008/98/EC, paper sludge waste should not be utilised in landfills. This article deals with paper sludge as sound absorbing material.

PS is generated in different technological processes in paper production or recycling chain. According to its composition of components paper sludge divided into two sludge groups:

Primary sludge – such sludge contains lignocellulose components (cellulose, lignin), binding materials of the paper (kaolin, calcium carbonate) [5], [6].

Ink sludge – such sludge contains ink from the recycled paper, small fibres of cellulose which cannot be regenerated for paper recycling, the remains of solution for ink removal [7], [8].

PS waste management problem becoming more important recent years in European Union and internationally. The PS waste is banned from landfilling in EU. Most of the PS in EU is not used for the recycling. According to Confederation of European paper industries only 10 % of PS was recycled in 2016 [9]. In Fig. 1 is shown that 55 % of PS is used for energy recovery which according to waste management guidelines is not good way to treat waste in long term.

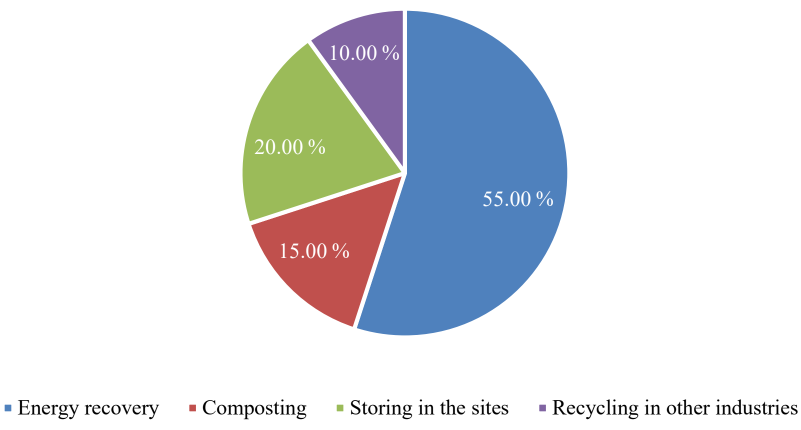

Fig. 1. Management of PS in European union, 2017 [9].

According to the recent studies PS could be used as raw material in several industry sectors:

– Biogas production. The PS contains from 45 % to 55 % percent of organic matter which shows that PS has potential for such waste treatment. Such data shows great

potential for PS to be used for biogas production [10]–[14];
- The other studies show that PS could be used for Biochar production. Such biochar could be used for soil treatment from zinc [15]–[17];
- In the construction materials. Most of the recent studies the PS potential to be used as additive for concrete to make the bricks lighter. The studies show that addition of PS to the bricks increase thermal insulation of the bricks, but reduces its robustness and strength [4], [18]–[21].

Most of the PS recycling is in the construction sector. Studies show that PS could be used for bricks to be made more porous. Such technique uses PS to create air gaps inside which reduced thermal conductivity. The technique air gaps are created during brick burning process, during this stage brick production PS burns and leaves air gaps inside the bricks. The downside of such technique that the strength of the brick is being reduced as well. Similar studies were performed with clay, ceramic bricks [22]–[23].

Another way to use PS is in the composite materials, several were made focusing on cement, wood chip composite with PS. Studies on composites containing PS and wood fibers, plastic or cement has shown that addition of PS reducing the overall strength of the composite. The optimal quantity of PS in most of the studies reach 10 % of overall mass [24]–[27].

Very few studies were made focusing on such composites acoustic properties. Most of the studies focusing on PS as additive to other known construction materials. This work focused on PS as main the material of the composite. In the most of other author works, the PS not considered as the main material in composite. The aim of this paper is to propose a method to produce PS and clay composite panels for sound absorption applications. The results gained in this study could be used in further PS composite development.

2. METHODS

PS used within the work was taken as a raw material from paper production company of Lithuania. The PS was obtained from different sides of the sludge pile. The sludge is a mixture of primary (pulp mill) and secondary (ink) sludges. The PS was dried at 60 °C in a drier and mixed every three days to achieve an effective drying process. The preparation of the paper sludge took 14 days on average, because of the high humidity of raw paper sludge. The dry paper sludge was crushed with a gill crusher and sorted. For PS composite panel sample making 1–2.5 mm grain size was used.

The proposed method to build up an acoustic panel made of PS composite using perforated boxes. In order to avoid the drawbacks related to the fragility and inhomogeneity of the composites. Lightweight, compact and robust acoustic panels designed for sound absorption applications.

Composites were obtained by mixing grains of PS and clay. To bind the clay and PS grains the water was used. While making clay and PS composite samples it was noticed that depending on clay quantity in the sample, the water quantity needed to make homogenous mixture changes as well. The mixture of clay and PS grains was dried in 50 °C for 3 days. To test sound absorption coefficient depending on composition of four samples were made by changing PS amount in the composition from 50–80 % in steps of 10 %. While preparing samples it was noticed that higher values of PS (90 %) is not appropriate, because sample do not bind good enough and becomes fragile. Therefore, acoustic properties of such sample cannot be tested due to its fragility.

A square sample box has been designed and 3D printed using polylactic acid (see Fig. 2a). The bottom of the container has been perforated with circular holes of 2 mm diameter in a square lattice of 3.5 mm. The function of the holes is to ensure the diffuseness of water drying.

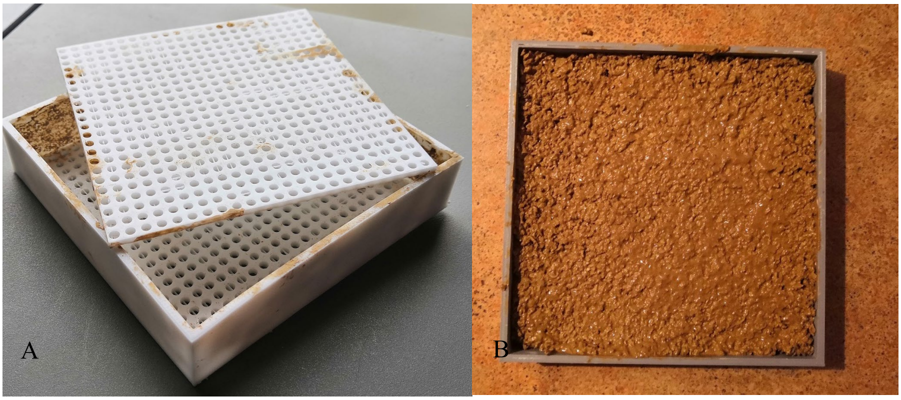

Fig. 2. Sample producing box. A) box with a top cover and B) box with the composite sample inside.

A top perforated layer has also been printed to close the box from the top. The samples were pressed and flipped every 2 hours during the drying period, this way the samples experience the gravity force from both sides, therefore clay do not travel to one side of the sample. The pressure of 120 Pa applied to the sample to ensure that the shape of the sample do not change while drying. In 3 days, a square acoustic panel of 10 cm^2 and 13 ± 1 mm thickness obtained using this container. In total 4 containers were used for sample making. In Fig. 3 dried PS and clay composite panels are presented. Due to its fragility, 90 % PS and clay composite panels were not tested, because it was nearly impossible to get representative data.

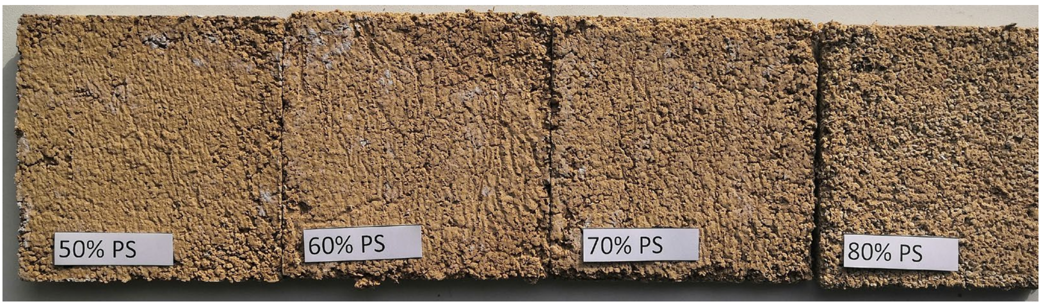

Fig. 3. Dried PS and clay composite panels.

For obtaining the sound absorption coefficient *(α)* of the paper sludge composites, the ISO 10534-2 standard method was used [28]. The cross section of the tube was squared of 10 cm side. Composite panels built to fit into the tube. The samples were rigidly backed. The experimental set up is shown in Fig. 4. The distances from the sample to the microphones are X_1 = 190 mm; X_2 = 100 mm and the distance between microphones S = 90 mm. The working frequency range is from 200 to 1600 Hz. The results are presented using 1/3 octave band filtering.

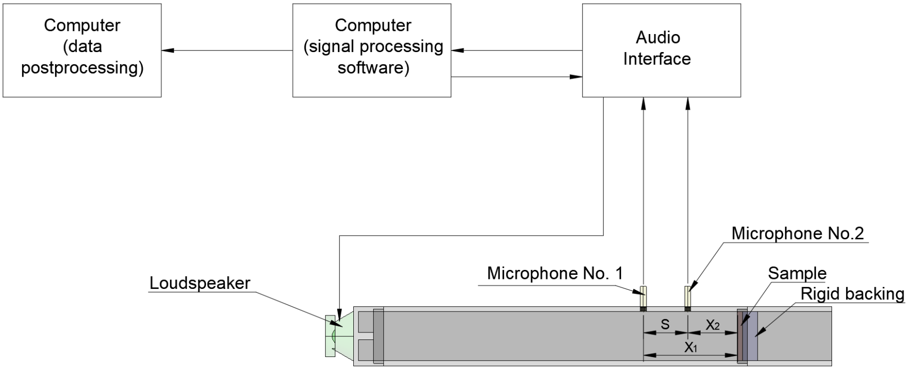

Fig. 4. Impedance tube system used for measurements. S = 90 mm, X_1 = 190 mm, X_2 =100 mm.

The tests were made according to the methodology described in ISO 10534-2 standard. Transfer function method was used, two microphone technique.

The transfer function H_{12} Eq. (1) between microphone positions calculated as the pressure ratio between pressures measured by both microphones. Transfer function for incident wave alone H_I and transfer function for reflected wave alone H_R calculated according Eq. (2) and Eq. (3) [28].

$$H_{12} = \frac{p_2}{p_1} \tag{1}$$

$$H_{\mathrm{I}} = \frac{p_{2\mathrm{I}}}{p_{1\mathrm{I}}} = e^{-\mathrm{j}k_0(x_1 - x_2)} \tag{2}$$

$$H_{\mathrm{R}} = \frac{p_{2\mathrm{R}}}{p_{1\mathrm{R}}} = e^{\mathrm{j}k_0(x_1 - x_2)} \tag{3}$$

From Eq. (1), Eq. (2) and Eq. (3) the reflection coefficient of the sample can be calculated as:

$$R = \frac{H_{12} - H_{\mathrm{I}}}{H_{\mathrm{R}} - H_{12}} e^{2\mathrm{j}k_0 x_1}, \tag{4}$$

where R is the reflection coefficient of the sample, k is the wavenumber, x_1 = 100 mm is the distance between the sample and microphone No. 1.

Finally, the sound absorption coefficient is calculated using the following Eq. (5).

$$\alpha = 1 - |R|^2 \tag{5}$$

The sound absorption is the inverse parameter to the sound reflection. Sound absorption and reflection parameters are relative to the total amount of energy, that falling on the material. These parameters vary from 0 to 1, and it is dimensionless.

3. Results and Discussion

Using the method described, four PS and clay composite panels were produced and tested. Due to different amount of clay in the composition the values of density vary between the samples. In table No. 1 the density parameters of the samples are presented.

In Table 1 it is shown that the density decreases as PS amount in the composite is increased. Such results show that composites with less amount of PS has a potential to be used for sound insulation applications.

TABLE 1. DENSITY OF PRODUCED SAMPLES

Sample No.	Percentage of PS in composite, %	Percentage of clay in composite, %	Density, kg/m^3
1	50	50	1098.8
2	60	40	886.9
3	70	30	752.6
4	80	20	627.9

In Fig. 5 the sound absorption results of different composite panels presented. The results of all samples show that sound absorption coefficient values increase with frequency. Low frequency values are low because of relatively small thickness (≈10 mm). The panels with lower PS quantity (50 %; 60 %) in the composition showed higher sound absorption coefficient values lower frequencies (250–1000 Hz). The sound absorption coefficient values of mentioned composite panels peaks at 1 kHz. Sound absorption coefficient of 50 % PS composite panel reach 0.48.

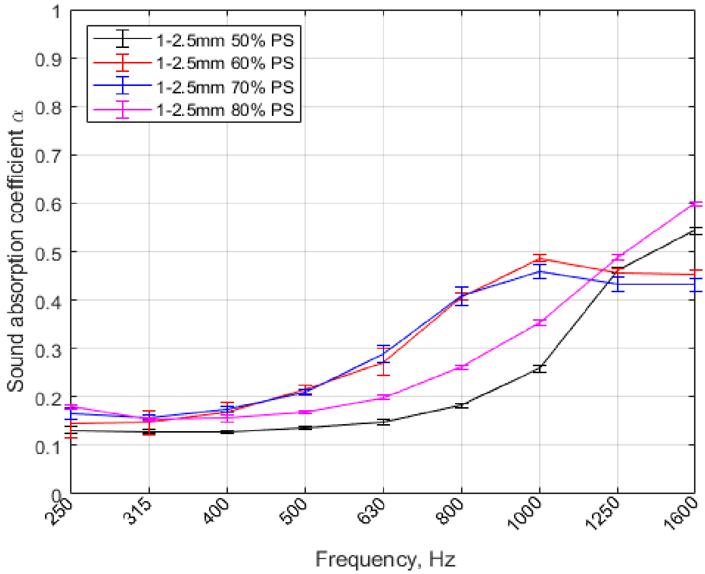

Fig. 5. Result comparison between composites.

Composite panel of 60 % PS showed similar behaviour compared with 50 % PS panel. The results show that sound absorption coefficient values increase with frequency. Similar to 50 % panels sound absorption coefficient is lower in lower frequencies. The sound absorption coefficient values start to increase from 630 Hz. Sound absorption coefficient α is highest in 1 kHz octave band and reach 0.5.

The panels with 70 % PS showed different behaviour compared with 50 % and 60 % panels. The results show that sound absorption coefficient values increase with frequency. The sound absorption coefficient values start to increase from 500 Hz. Sound absorption coefficient α is highest in 1.6 kHz octave band and reach 0.55. Due to limitations of measurement equipment the peak values of this composition were not found. Potentially the peak values of this composition are in higher frequencies.

The composite of 80 % PS showed similar behaviour to 70 % PS composition. The results show that sound absorption coefficient values increase with frequency. The sound absorption coefficient values start to increase from 500 Hz. Sound absorption coefficient α is highest in 1.6 kHz octave band and reach 0.59. As with 70 % composite peak values were not found.

When comparing all tested composites, the results show that composites with less PS in it absorb sound better in lower frequencies (250–1000 Hz) but less in higher (1250–1600 Hz). Such behaviour could be linked to higher density of samples which had less PS in its composition.

The tested PS and clay composites showed similar results in lower frequencies, up to 500 Hz. Such similarity depends on thickness of the sample. It is well known that sound absorption is efficient in ¼ of wavelength. Since the sample thickness was kept constant, (13 ± 1 mm) the sound absorption composite sound absorption in lower frequencies were similar.

In higher frequencies, from 500 Hz to 1.6 kHz the sample behaviour varies. Such difference could be addressed to porosity changes due to change of composition of clay and PS. The best sound absorption values were found when testing composite with 80 % PS (α reach to 0.59).

The proposed method shows that it is possible to design the panel which works for sound absorption applications. In further studies different PS grain size will be investigated. It is known that granular media porosity greatly depends on grain size, such phenomenon needs investigation of PS with clay composition.

Even though the method to produce PS and clay composite panels was proposed, it needs further investigation. It was noticed that several samples were uneven and needed remaking. The process of sample making will be adjusted in further studies in order to achieve panels with perfectly even walls. Such limitation of sample making can be seen in Fig. 5 and Fig. 6, where sound absorption coefficient slightly decreases in higher frequencies. Such phenomenon shows that there was very small air gap behind sample while measuring due to not even back surface of the sample.

4. CONCLUSION

With this study proposed method to produce robust acoustic panels where the main material is PS. Using clay as binder allowed to make samples, which was robust enough to test them without any difficulty. Although decreasing clay quantity in composition showed that samples became fragile. The proposed method shows the potential way for PS to be recycled.

The sound absorption coefficient values increase when density of composition decreases. The study shows that 50–60 % PS samples are too dense to achieve effective sound absorption. The optimal sound absorption coefficient values were found in 80 % PS composite (α reach to 0.59). For sound absorption application such panels could be used with air gap behind panel to achieve better sound absorption with the same panel.

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