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Physical mechanical and acoustic properties for composite materials made from construction and demolition waste

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Abstract
Environmental protection is an essential human problem and that is why most countries in the world are taking measures to limit it. As we know, pollution is contamination with materials that damage health, quality of life, or the natural functioning of ecosystems. Although some environmental pollution is a result of the action of nature, most are caused by human activity. The disposal of waste from various industrial processes affects the quality of the environment. A particular current problem with environmental pollution is waste as a whole, including construction and demolition waste. Another current problem is noise pollution with negative effects on humans. In this paper, these two problems are addressed through the valorization of these types of waste and the production of composite materials with sound-absorbing properties. Six types of construction and demolition wastes are used and subjected to physical-chemical analysis to determine their moisture content, particle size, and chemical composition. Through an optimized technological process, composite materials were obtained and their sound absorption capacity was determined.

Keywords: *environmental pollution, composite materials, sound absorbing materials, waste, noise pollution*

INTRODUCTION

Today, environmental protection is a major problem for humanity, and most countries in the world are taking measures to limit pollution. International conventions have been signed which harmonize these measures. Environmental protection issues are particularly complex and concern all sectors of activity: economic, social and political [1]. Historically, environmental pollution began with man, but it has developed and diversified as human society has evolved, becoming today one of the major concerns of specialists in various fields of science and technology, of states and governments, and of the entire population of the earth. Although part of environmental pollution is a result of the action of nature, most of it is caused by human activity [2]. Economic development brings with it concerns about environmental protection in general, and noise in particular. Therefore, noise pollution is of interest primarily for its current aspects, as it still creates nuisance, damage and health impacts, sometimes involving large masses of people through exposure to noise at disturbing, stressful or harmful levels. The widespread use of electrical and mechanical appliances in the home and in industry, and increasingly heavy road traffic, has led to the development of noise reduction research. This can be reduced by using different materials that reduce sound pressure levels by absorbing sound waves or by attenuating them [3-7]. A particular current problem of environmental pollution is waste as a whole, including construction and demolition waste. Although the reuse of demolition waste has been studied in recent years, its reuse in composites has not been investigated in detail. In general, the studies aim to provide a comprehensive review of the literature on the possible uses of reused construction and demolition waste in the manufacture of composites. Also, recycling of materials in the economy can lead to a reduction of production costs on the one hand and on the other hand, recycling of such wastes is often seen as a means to mitigate climate change by avoiding the use of virgin raw materials [8]. The research is based on the use of recycled wood, paper, cardboard, metal, glass, mineral glass, gypsum, precast concrete and ceramics as raw materials for composites. Oxide composition, contamination due to various agents, degradation and recycling of building materials is discussed to explain the potential of obtaining composite materials. Most of the researches refer to recycled construction waste and the composites obtained have been made on thermoplastic materials combined with cellulose-based fibers as well as mineral wool and gypsum [9-12]. There is a permanent concern about obtaining types of materials with superior properties to the classical ones (composite materials) whose use can cover different fields, among which of great importance is the reduction of environmental pollution. Often the materials used for noise reduction are composites, where sound insulation is expressed by their ability to prevent the transmission of sound energy. Thus, over the past decades, researchers around the world have increasingly turned their attention to waste as a result of various technological processes in industry. A number of researches on waste management have been published in various academic journals [13-16]. The present paper addresses a topic of particular importance with environmental and economic impact: construction and demolition wastes are used as raw materials to obtain composite materials; by-products with high environmental impact are reused.

This work represents research on the physical-mechanical characterization of composite materials with sound-absorbing properties obtained from various construction and demolition wastes. Through a series of laboratory tests, an optimal technological process was achieved, with the help of which composite material samples were obtained. The samples were tested in terms of mechanical compressive strength, density and apparent porosity, sound absorption coefficient. Based on SEM electron microscopy microstructural analyses, the structure-property correlations of these composite materials with various wastes are presented. The studied wastes are of organic nature: wood and plastic waste or inorganic (oxide waste): brick waste, gypsum board, concrete and ceramic waste. The aim is to obtain composite materials by combining the selected wastes and using ground concrete as a binder matrix activated with $CaCl_2+CaO$ in order to obtain a system with a sufficient degree of hardening [17-21]. The other types of waste are also used as reinforcing agents.

MATERIALS AND METHODS

Figure 1 shows the types of waste used in this work, in order to elaborate and study them from the point of view of their physical-mechanical and noise properties.

Fig. 1. Types of waste used to obtain composite materials

Selected wastes were subjected to drying according to SR 5264:1995 [22]. The total moisture was determined by summing the soaking moisture $W_î$ and the hygroscopic moisture, W_h according to relation (1), and the resulting values are shown in Table 1.

$$W_t = W_î + W_h \quad (1)$$

where: $W_î$ – soaking humidity; W_h – hygroscopic humidity

Table 1. Total humidity determined for the studied waste

Sample	Waste type	Total humidity, W_t (%)
S1	wood	36,42
S2	brick	48,75
S3	plastic	53,20
S4	drywall	55,44
S5	concrete	50,02
S6	ceramic	49,86

Drying has become necessary mainly because of the storage conditions of these materials. After drying, waste with large grain size was subjected to grinding (for waste such as brick, plastic, concrete and ceramics) according to ISO 2591-1: 2003 [23]. Wood waste is in the form of noodles. After grinding, the waste identified in this work was analyzed in terms of particle size distribution by sieving for the coarse fraction according to EN-933-1:2002 [24].
The sieving operation was carried out with the Verder A5200 basic machine on which a maximum of 8 sieves can be mounted. The fine fractions were identified using the MALVERN, MASTERSIZER 2000 laser beam particle sizer according to ISO 13320-1 : 2001 [25]. It was aimed for all the mentioned wastes to have a well controlled particle size distribution to ensure the reproducibility of the data obtained. The chemical composition of the waste used was also studied and determined with a spectrofluorimeter. Therefore, XRF analyses were carried out using a Rigaku CG analyzer (Rigaku, Japan) equipped with 50W X-ray source with Pd anode and Al, Mo, Cu and RX9 (HOPG polarizer - highly oriented pyrolytic graphite) secondary targets. The choice of secondary targets was done automatically, depending on the elements analysed. Detection was performed using a silicon drift detector (SSD) maintained at optimal temperature by means of a Peltier system. To perform the determinations, calibration with internal standard was initially performed. The samples were previously calcined at 5500C and homogenized using a mill. No sieving was necessary due to the small particle size of the sample. Approximately 3 g of dried sample was introduced into polypropylene cups (diameter 32 mm) equipped with transparent Prolene® film, after which they were analyzed according to EN 15309/2007 [26]. For characterization of the sound absorbing properties of the obtained composite materials, known methods were used, according to current standards. Thus, the determination of the sound absorption coefficient was carried out with Kundt tube acoustic interferometer according to ISO 10534-1; ISO 10534-2 [27, 28] according to the scheme in Figure 2, [29].

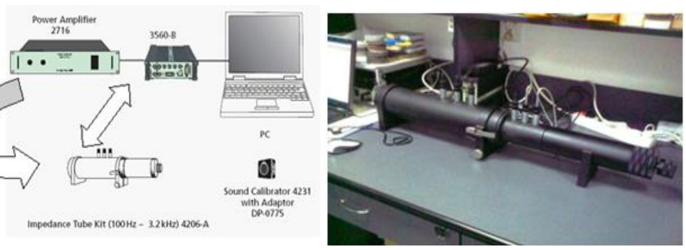
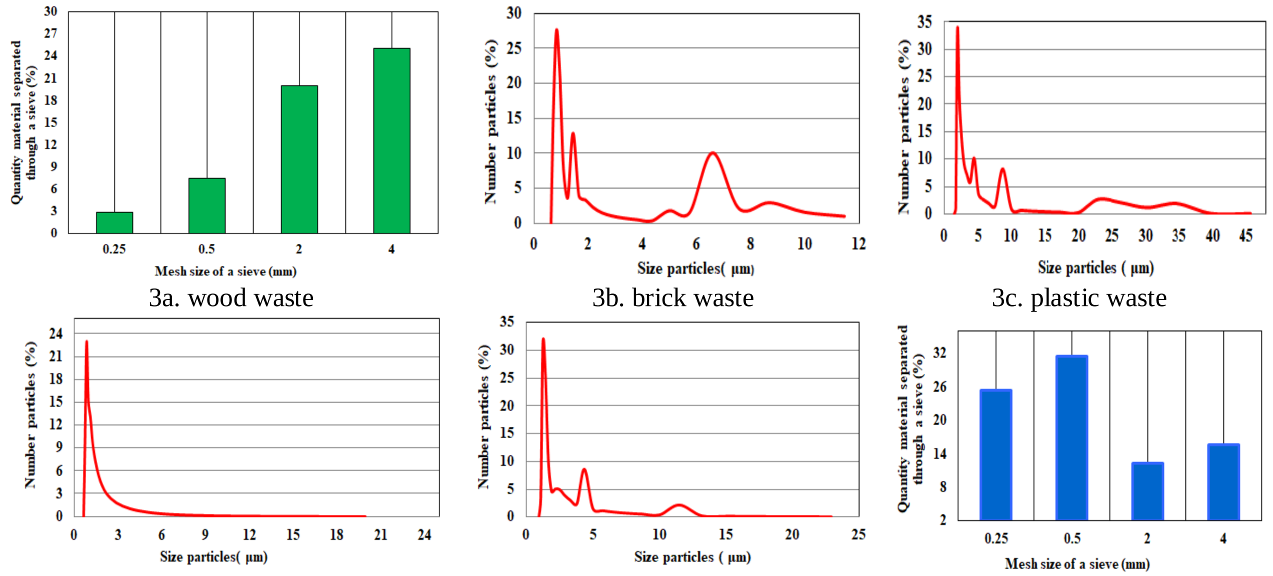


Fig. 2. General scheme of the acoustic interferometer measuring system

Also, compressive strength, apparent density and apparent porosity were measured according to the respective standards [30, 31]. Compressive strength was performed according to EN 826:2013. Electron microscopy images, showing the structure of the oxide materials obtained, were taken using the QUANTA INSPECT F scanning electron microscope (SEM) equipped with a field emission gun (FEG) with a resolution of 1.2 nm and an energy dispersive X-ray spectrometer (EDS) [32].

EXPERIMENTAL PART

The particle size distribution for the studied wastes is shown in Figure 3 for both coarse and fine fractions: wood waste Figure 3a, brick waste Figure 3b, plastic waste Figure 3c, plasterboard Figure 3d, concrete Figure 3e and ceramics Figure 3f.



3a. wood waste 3b. brick waste 3c. plastic waste

3d. drywall waste 3e. concrete waste 3f. ceramic waste

Fig. 3a-3f. Particle size distribution for waste used

The chemical composition of these studied oxide wastes (average values, gravimetric %) is presented in Table 2.

Table 2. Chemical composition of oxide waste

Type of oxide	(%) gravimetry/waste			
	brick waste	plasterboard waste	concrete waste	ceramic waste
SiO_2	55.58	7.80	22.66	18.52
Na_2O	2.65	2.76	0.88	0.64
K_2O	0.30	0.12	1.26	1.05
MgO	12.65	9.65	8.56	6.22
CaO	0.55	75.63	12.38	25.63
Al_2O_3	12.88	2.88	45.32	44.03
Fe_2O_3	15.39	1.16	8.94	4.18

The composite samples were made according to the technological process shown in the scheme in Figure 4. In the first phase the waste materials used as raw materials are dosed gravimetrically to the established proportions in a container resistant to mechanical shocks. While homogenization is taking place, other materials that influence the hardening of the samples and their porosity are added. The wastes used as raw materials are characterized as cementitious materials and as such have latent binding properties. Thus, in order to influence the hardening of the binder system and to obtain composite samples, a mixture of $CaO+CaCl_2$ was added as an activator. After homogenization, the mixture is poured into the previously prepared mold. After a 24 hour hardening period the sample is removed from the mold by stripping, and then the samples thus obtained are left to harden. Table 3 shows the 5 samples developed and studied in this work, in terms of their physical-mechanical characteristics.

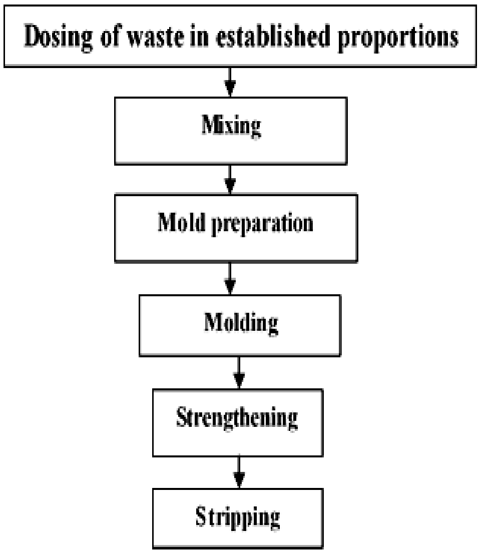


Fig. 4. Schematic of the technological process for obtaining composite materials

Table 3. Chemical composition of oxide waste

Waste used	Sample no.				
	S1	S2	S3	S4	S5
Wood – reinforcing material	10%	40%	20%	---	---
Brick – reinforcing material	28%	---	10%	20%	---
Plastic – reinforcing material	---	8%	---	20%	30%
Drywall – reinforcing material	---	10%	8%	18%	20%
Concrete – liance matrix	40%	30%	30%	30%	40%
Ceramics – reinforcing material	20%	10%	30%	10%	8%
CaO+CaCl2 – activator for hardening	2%	2%	2%	2%	2%
Total	100%	100%	100%	100%	100%
Solid material to water ratio	1: 0.35	1: 0.35	1: 0.35	1: 0.35	1: 0.35

RESULTS AND DISCUSSION

Figure 5 shows the graph for the determination of the sound absorption coefficient for the 5 samples developed. A range for the sound wave frequency between 16-3150 Hz was worked.

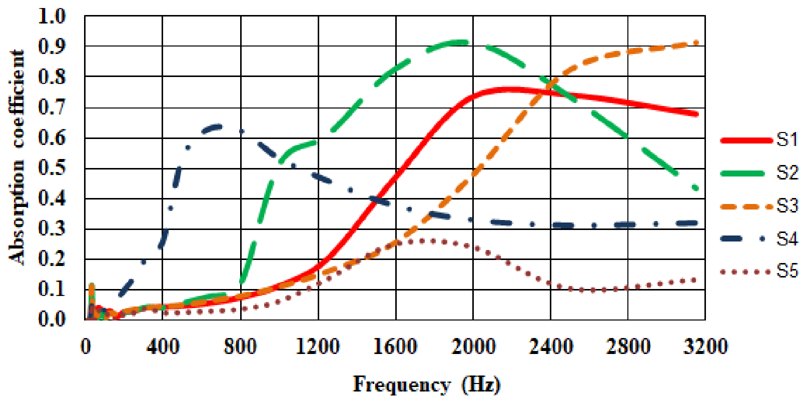


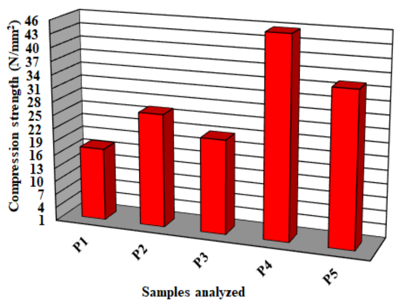
Fig. 5. Sound absorption coefficient depending on the frequency five samples

A better absorption of sound waves than the other samples is observed for sample 2. Thus, the sample reaches a maximum absorption $\alpha = 0.92$ in the high frequency region at 2000 Hz. This is due to the desurilot used to obtain the composite material that gives porosity to the sample - 40% wood was used in mixture with brick and ceramic.

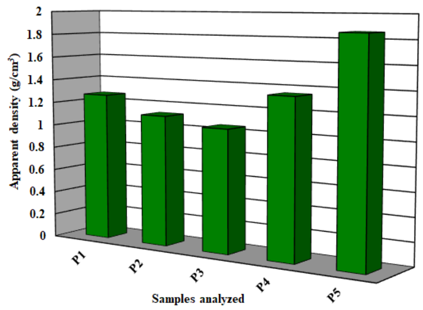
Sample 3 shows a sound wave absorption of α = 0.90 at frequent high frequencies of 3000 Hz. In the case of this sample, a lower percentage of wood waste without brick but with 30% ceramics was used in its manufacture.

For sample 1 a lower sound absorption is observed compared to samples 3 and 2 so that in the frequency range 1200-2400 Hz it reaches a maximum of α= 0.75 at 1800 Hz. Samples 4 and 5 have the lowest sound absorption coefficient.

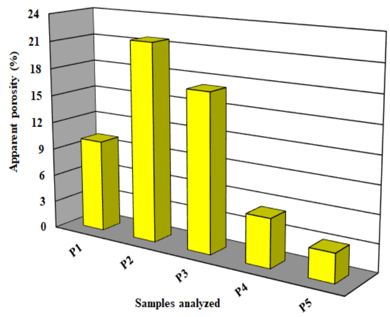
The samples were tested in terms of mechanical compressive strength, density and apparent porosity and the test results are shown in Figures 6a-6c.



6a. Compression strength



6b. Apparent density



6c. Apparent porosity

Fig. 6. Waste characteristics: a) compression strength; b) apparent density; c) apparent porosity

Figure 6a shows better compressive strengths for samples 4 and 5 compared to the other samples. This is due to the compaction of the material, but it is detrimental to the sound wave absorption property. In addition to the binder matrix, i.e. concrete, a percentage of other non-wood waste in the form of noodles was used as reinforcement material in the mix. As such, compactness results in better compressive strength at the expense of sound wave absorption. Figure 6b shows a higher apparent density in samples 4 and 5 compared to the other samples. This is due to the fact that the samples are more compact and as such denser. The explanation lies in the type of matrix binder-reinforcement material mixture which results in a higher apparent density for samples 4 and 5. As for the apparent porosity shown in figure 6c, higher values are observed for sample 2. In this case, the fact that a higher percentage of wood veneer with added brick and ceramics was used in the production of this type of composite material, causes the formation of those voids/pores, which in addition to the higher values for the determination of the apparent porosity is also influenced by the absorption of sound waves.

Figures 7a-7e show SEM electron microscopy images (at 2 different magnifications) for the developed composite materials.

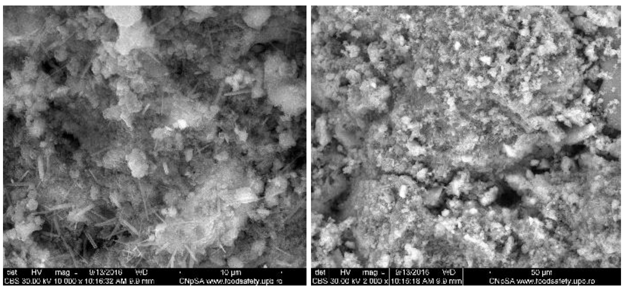


Fig. 7a. S1 SEM electron microscopy (10-50 µm)

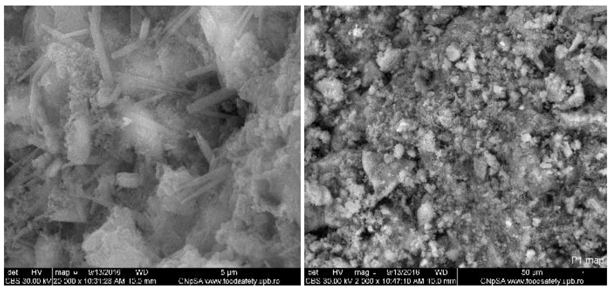


Fig. 7b. S2 SEM electron microscopy (5-50 µm)

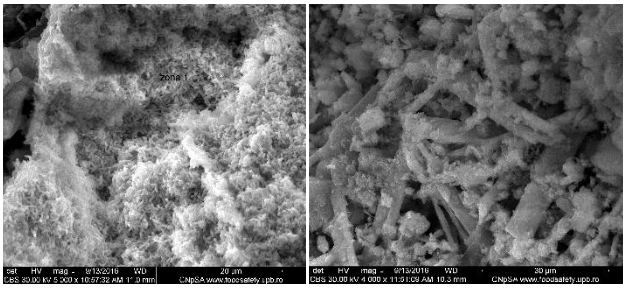


Fig. 7c. S3 SEM electron microscopy (20 µm)

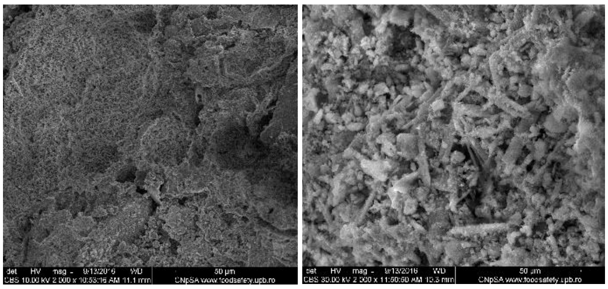


Fig. 7d. S4 SEM electron microscopy (50 µm)

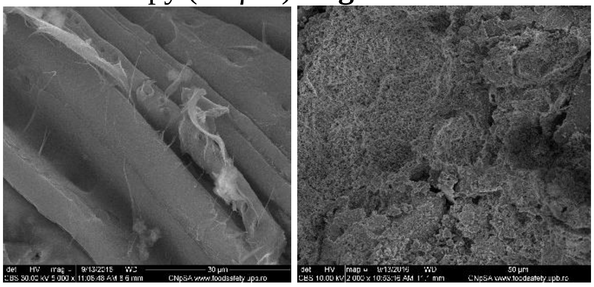


Fig. 7e. S5 SEM electron microscopy (30-50 µm)

As can be seen from Figures 7a-7e, SEM electron microscopy analysis is necessary to study the microstructure as well as the surface roughness of the materials processed. Therefore, by this analysis method, the existing inhomogeneities and pores have been highlighted in order to demonstrate the physical-mechanical and phonic properties. Thus, for samples 3, 2 and 1, more and larger pores are highlighted which determine both the porosity and the sound wave absorption. For samples 4 and 5 in the SEM electron microscopy images a smaller fraction of pores is observed. This is due to the compactness of the samples. More compact samples with higher density and therefore higher mechanical strength. But as far as sound wave absorption is concerned, it is also very low due to the small pore fraction. So from the SEM electron microscopy analysis it is found that the porosity of the samples is in agreement with the determinations for apparent density apparent porosity and thus indirectly confirms the values for mechanical compressive strength as well as sound wave absorption.

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CONCLUSIONS

The aim of this work was to obtain composite materials with sound-absorbing properties from construction and demolition waste, based on an optimized technological process. The basic material was waste concrete used as a binder matrix, and the other materials were waste wood, brick, plastic, plasterboard and ceramics. Determinations of the physical-mechanical properties showed different values depending on the proportion of waste used to obtain the samples. Therefore, as far as the compressive strength is concerned, sample 4 showed the highest value compared to the other samples, and this is due to the mixture of oxide waste used to obtain the composite material. Thus, a sample was obtained whose compactness gives it mechanical strength. For the apparent density, high values were determined for sample 5 due to the fact that a compact sample was obtained in which a higher percentage of concrete was used as a binder matrix. The determination of the apparent porosity showed sample 2 with the highest value compared to the other samples and this is due to the use of a higher percentage of wood waste in the mixture. The values of the sound wave absorption coefficient determined indicated which composite materials are the best performing in terms of sound absorption. A correlation was also observed for the compressive strength, density and apparent porosity tests for the samples obtained. SEM microscopy analyses confirm the determined physical-mechanical and sound absorbing properties and allow a reasoned selection of the obtained materials.

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