POLYTECHNIC UNIVERSITY OF BUCHAREST

Faculty: MECHANICS AND MECHATRONICS
Department: EQUIPMENT FOR INDUSTRIAL PROCESSES
Doctoral school: MECHANICAL AND MECHATRONIC ENGINEERING

PHD THESIS SUMMARY

"RESEARCHES ON THE MECHANICAL AND SOUND ABSORBING CHARACTERISTICS OF COMPOSITE STRUCTURES REINFORCED WITH FIBERS OR PARTICLES"

Author: NIȚU (SPÂNU) SILVIA - ANDREEA
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CONTENT

INTRODUCTION

The actuality of the thesis topic

Currently, great efforts are being made to identify optimal solutions in the case of waste management and the reduction of carbon dioxide emissions produced by various sources **[49, 68 – cap. 2].**

The issue of climate change is intensively studied by researchers, studies that have resulted in numerous scientific articles addressing both the factors that led to the appearance of these phenomena, as well as the potential methods of adapting to climate change and reducing its effects on population and the environment. Climate change can be caused by both natural and anthropogenic causes **[1 - cap. 1].**

In population life, at the current stage, noise pollution is of particular interest. The noise produced outside a home, an industrial hall or a commercial space, by equipment represents a significant problem for the health of the population. Among the main sources that produce environmental noise are the following human activities: road traffic, public works, railway traffic, air traffic and other human activities carried out in various branches of industry.

The studies developed in the field show the fact that the intensity of street noise and noise in people's homes exceeds, most of the time, the maximum allowed values, which leads to the appearance of cardiovascular, neuropsychic disorders and even a total discomfort of both the human and the other creatures living in these areas. Noise pollution can be produced by natural causes, such as: earthquakes, volcanic eruptions, etc.

Pollution can also be produced by artificial causes, such as: human activities, especially transport and industrial activities, which are loud and long-lasting noises that exceed the maximum values allowed by the legislation in the field. People interpret noise differently, but they are all negatively affected by high noise levels; it even leads to the production of traumas of the auditory apparatus **[37 - cap. 2].**

A solution to reducing the amount of waste and the noise level, as well as protecting populsation and the environment, could be the creation of new composite materials from materials obtained by recycling waste.

The concept of composite material is not new, it is even an old concept from a historical point of view. After 1970, composite materials began to be used frequently in many economic fields, for automobiles, sports goods or in medicine, etc. **[1 - cap. 3].**

Composite materials appeared in the context of the need to replace the existing basic ones: ferrous or non-ferrous, materials that do not have the most optimal characteristics in terms of: methods of obtaining and recycling, areas of use, costs or masses. These materials have anisotropic properties, and through the method of obtaining and processing, they allow the use of the best characteristics possessed by the materials from which they are produced **[3 - cap. 3].**

In conclusion, the composite materials obtained and studied within the present thesis represent a current topic, these materials representing the future in terms of resources.

The importance of the thesis topic

In the context of the existing global problems regarding climate change, environmental pollution and the risk of population disease, it is necessary to identify optimal solutions to combat them.

According to specialist studies, nowadays composite materials are increasingly used in various fields, due to their superior mechanical and physical properties **[17-21 - cap. 3]**. Composite materials also possess acoustic and thermal properties, a fact scientifically proven over time through numerous experimental researches carried out in this field **[22 – 23 - cap. 3].**

The characteristics of composite materials are highlighted by advantages in terms of thermal deformation factor, volumetric, transversal or longitudinal modulus of elasticity, mass percentages, thermal conductivity, thermal properties or mechanical resistance to compression or tension **[2 - 8- cap. 3].**

In conclusion, composite materials present a great advantage, namely the fact that there is the possibility of modulating their properties and thus, a variety of materials with superior properties and with various uses can be obtained.

General objectives of the thesis

The present research paper addresses the possibility of obtaining composite structures from waste with superior mechanical properties and an increased sound absorption coefficient, of different sizes and compositions. The determination of the absorption coefficient in the framework of the experimental research carried out in this thesis was realized with the Kundt tube. The results presented by the biocomposite structures obtained and studied indicate that the values of the sound absorption coefficient are directly influenced by the nature of the materials in the composition, but also by their thickness. From the interpretation of the obtained results, it emerges that the composite materials have sound-absorbing properties and sound-absorbing panels can be made from them, which can be used in different fields with the aim of reducing the noise level.

To achieve the objectives, the thesis is structured as follows:

- identification of the current stage in the specialized literature related to the field chosen for research;
- procuring and processing the necessary materials for obtaining experimental samples;
- obtaining the experimental samples;
- subjecting the experimental samples obtained to the Kundt tube in order to determine the values of the sound absorption coefficient for each individual sample;
- recording and processing of the obtained data;
- the interpretation of the results obtained by each experimental sample obtained and evaluated in this thesis;
- the preparation of scientific articles or communications within conferences for the dissemination of the obtained results.

The experimental part of the paper/thesis is structured in two stages, respectively: the first stage includes the establishment of the methodology for obtaining experimental samples (compositions, thickness, quantity), and the second stage includes the collection and interpretation of the data obtained by subjecting the samples to the Kundt tube and the dissemination of these results.

C H A P T E R 1

HISTORY OF CLIMATE CHANGE. CAUSES, EFFECTS AND TECHNICAL SOLUTIONS TO REDUCE THE EFFECTS OF CHANGES CLIMATE ON POPULATION

1. 1. The history of climate change

1. 1. 1. Overview

Climate change is a complex problem with **global implications [1].**

Currently, humanity is facing the phenomenon of global warming, which appeared mainly due to anthropogenic activities, which highlights the fact that people are in reality facing two problems, namely: identifying optimal solutions for reducing harmful emissions and at the same time identifying optimal solutions for adaptation of both population and natural ecosystems to the effects of climate change **[2].**

Emissions of CO_2 have the largest contribution to the production of the total amount of aggressive emissions; as a result, more importance must be given to investing in new technologies and in improving energy efficiency, in raising the awareness of human society regarding the responsible consumption of all natural resources and in obtaining substitute materials through the waste recycling method **[3].**

1. 1. 2. The causes and effects of climate change

The increase in the amount of pollutants as a result of human activities has a direct effect on the increase in the average global temperature. These emissions, although they allow solar energy to penetrate, do not allow it to be released from the atmosphere. Therefore, there is a significant increase in global temperature, which leads to the occurrence of extreme phenomena such as: melting of glaciers, rising sea levels, floods and even droughts in certain regions **[5].** Among the activities that lead to an increase in the volume of harmful emissions are listed: excessive consumption that generates large amounts of waste, raising animals and decomposing their excrement, the transport industry, uncontrolled deforestation, etc. **[6].**

The effects of climate change are felt globally, more and more intensively, with each passing year, which leads to the need to make efforts by all the states of the world to **identify solutions** for adapting to these changes.

1. 2. Waste

1. 2. 1. Overview

The amount of waste generated by human activities represents a **problem** that has been recognized since the last century, when it was found that their treatment methods, such as **incineration and storage, are not effective**. **Recycling the materials** that make up waste is **a more efficient and environmentally friendly method**. The main characteristic reasons for recycling have in mind the economic advantage and the reduction of the amount of natural raw materials used in human activities **[17].**

Waste management is a necessary problem at the global level, on the one hand by increasing their quantity, as well as by the negative impact they can have.

In Europe, waste collection is done under the motto of the three R's (Reduce, Reuse and Recycle). In Romania, the initiative did not produce the expected results.

1. 2. 2. Waste treatment methods

1. 2. 2. 1. Collection and transport of waste

For the waste collection process, the following aspects are important: the frequency of waste collection, the volume and type of container and the combination of containers, these factors directly influencing the quality and quantity of recyclable materials. For recyclable materials, collection is selective, in separate containers **[26].**

Waste transport is classified into two categories, short distance transport (from source to disposal or transfer facility) and transfer station and long distance transport from recycling, disposal or treatment facility/transfer station to a facility recycling, disposal or treatment plant. Waste is transported by rail, sea or road transport. In Romania there are 3 types of transport according to the degree of loading of the vehicles. Such means for transporting waste must be able to load as large a quantity as possible, argued by economic aspects.

The method of waste collection and transport plays an important role in the process of reducing the amount of waste through its recycling.

1. 2. 2. 2. Biological treatment of waste

Biological treatment can be considered a recycling method considering that the result of biological treatment is "compost", and this can be used as a fertilizer for agricultural land or as a pre-treatment step of waste prior to the process of storage or incineration. At the same time, biogas can be obtained by applying anaerobic digestion. Following the application of anaerobic digestion of waste, a mixture of gases results, such as: methane and carbon dioxide **[28].**

The biological treatment of waste presents numerous advantages both for the environment and for people's health, contributing to the reduction of the amount of waste existing globally by obtaining natural fertilizers for soils or by obtaining biogas **[35].**

1. 2. 2. 3. Mechanical waste treatment

1. 2. 2. 3. 1. Waste shredding techniques

Waste shredding is the process by which large volume units are transformed into small volume units under the action of mechanical forces **[36].**

Regardless of the properties possessed by the solid waste, the type of force acting on it or the equipment used, the shredding stage occupies an important place in the process of mechanical waste treatment.

1.2.2.3.2. Waste sorting techniques

The technical procedures used for the dimensional, optical, magnetic, densimetric, manual separation of waste are detailed in the papers **[39, 40**].

Sorting facilities aim to separate fractions that can be recycled from waste mixtures, such as: paper, PETs, glass, cardboard, wood and metals **[25].**

1.2.2.4. Bio-mechanical waste treatment

For the biological treatment of waste, several combinations of technologies can be used depending on the quantities, chemical and physical properties possessed by the waste. The result is biostabilized material for landfills that consumes a large proportion of landfill space, poor quality compost, biogas for heat and electricity generation **[42, 43].**

The bio-mechanical treatment of waste represents an effective method of treatment that contributes to the reduction of the amount of waste existing globally as well as to the protection of both the environment and human health.

1. 2. 3. Waste recycling

1. 2. 3. 2. Trends and advantages of waste recycling

An important problem of humanity at the moment is waste management. There is a well-recognized trend of waste recycling, with the advantages recognized unanimously **[50-56].** In Europe, it is desired to reduce both the quantities of stored waste and the number of existing landfills **[35].**

The identification and implementation of waste treatment methods for the recovery of energy and materials is a current global concern.

1. 2. 4. Waste in the context of climate change

On a global level, intense efforts are being made to identify optimal solutions in the case of waste management and the reduction of carbon dioxide emissions, produced by various sources **[49,68].**

Waste could be effectively used as sources of new raw materials. In this way, the amount of natural, extracted and processed raw materials can be reduced. The transformation of waste into an important resource implies, on the other hand, the elimination of deposits and, at the same time, the blocking of illegal transports.

It can be concluded that waste management is an important component in the context of climate change.

C A P I T O L U L 2

ACOUSTICS AND THE IMPACT OF NOISE ON HUMAN HEALTH

2.1. Environmental pollution

2.1.1. Overview

Pollution is a complex process that can introduce gaseous, liquid or solid products, generally harmful or harmful, into the air, soil or subsoil **[1].**

Water infestation produces undesirable biological reactions on humans, in particular, but also on plants and animals. The state of the water-infested soil influences water sources, both surface and underground. Air pollution with gases or solid particles, respectively with liquids, cannot be neglected **[2].**

2.1.2. Noise pollution

The vibrations of the particles of an environment materialize through sounds transmitted in the form of elastic waves. The factors influencing sound propagation are: distance, obstacles encountered, noise source and atmosphere. Noise represents a disordered overlap of several sounds, it can be the result of both natural and anthropogenic causes such as: people, means of transport, machines, etc. Noise has negative effects, especially on population **[13].**

Currently, there is a tendency to increase the level of noise due to the development of the branches of industry, and therefore the environment in which the population carries out its activity and its health are negatively affected more and more **[16].**

2.2. The noise

2.2.1. Overview

Among the main sources that produce environmental noise are the following human activities: road traffic, public works, rail traffic, air traffic or human activities carried out in various branches of industry.

The level of noise and sound pressure can be measured with the help of the equipment called ***"sonometer".*** It can determine the noise level both in people's homes, shopping centers, office buildings and industrial halls.

In order to protect people and the environment, a continuous monitoring of the noise level is necessary. Considering the fact that environmental noise is everywhere and that the population cannot avoid it, it leads to the need to identify optimal solutions to reduce the level so that the population is not affected **[23].**

2.2.2. Noise in SMEs

In order not to damage the auditory system and for the protection of employees in SMEs, a maximum noise level has been established, i.e. 87 dB(A), regulated by legislation **[26].**

In order to ensure the maintenance of the noise level below the maximum threshold allowed by law and to reduce it if the threshold is exceeded, employers must use some solutions: the assessment of risk factors and, depending on the result of these assessments, to implement preventive measures of these risks, the periodic analysis of the measures implemented to verify their effectiveness **[27].**

2.3. Oscillations and acoustic waves

2.3.1. Oscillations

Oscillatory movement is a periodic movement that repeats itself regularly at equal intervals of time, being one of the most well-known movements in nature. Oscillating systems have two simple operational models. The first operational model is the mathematical pendulum, a small body suspended in the gravitational field by a wire or rod of negligible mass. The second operational model is represented by the elastic pendulum, a body connected to the end of a spring of negligible mass **[30].**

2.3.2. Waves

2.3.2.1. Overview

"Waves are defined as the propagation in time and space of a disturbance. Energy is transported from the place of production to the outer space. Waves can be classified according to their nature into **[33]":** mechanical waves, gravitational waves and electromagnetic waves.

2.3.2.2. Mechanical waves

2.3.2.2.1. Overview [33]

Mechanical waves differ from other types of waves in that they propagate only in continuous media (liquids, solids, gases). When the particles of the medium oscillate, they also cause the particles in their vicinity to oscillate. The oscillation propagates from one particle to another (neighboring particle).

2.3.2.2.2. The wave equation [33]

The wave is defined by the mathematical expression:

$$\psi(x) = \psi(x + \lambda), \qquad \textbf{(2.6)}$$

2.3.2.2.3. Energy carried by waves [34]

The disturbance, in the propagation process, generates a transfer of energy and not a transfer of substance. The average energy density of the wave, respectively ω, the energy per volume unit of the medium in which the wave propagates is expressed by the relation:

$$\omega = \frac{1}{2}\rho\omega^2 A^2 \qquad \textbf{(2.7)}$$

The energy flow of the wave, respectively *W*, that passes through some surface in unit time is expressed by the relation:

$$\frac{\partial w}{\partial t} = Sv\omega, \qquad \textbf{(2.8)}$$

2.3.2.2.4. Wave dispersion. Group speed [34]

The propagation of a set of waves of close frequency to each other forms a wave packet or group of waves.

The speed of movement of a point of constant amplitude (Fig. 2. 10), is expressed by the following relationship:

$$d\omega t - dkx = constant \qquad \textbf{(2.9)}$$

By derivation with respect to time, the group speed is determined, v_g, of the package where:

$$vg = \frac{dx}{dt} = \frac{d\omega}{dk} \qquad \textbf{(2.10)}$$

2.4. The impact of noise on human health and specific legislation

2.4.1. Overview

Nowadays **noise pollution** has become one of the main forms of pollution due to the fact that it **affects the health of people**, sometimes even a large mass of people. People interpret noise differently depending on their health or age, but they are all negatively affected by the high intensity of noises, even reaching the production of hearing trauma **[37].**

2.4.2. Specific legislation

At the level of the European Union there are numerous noise regulation directives, among them **[49]:**

- Directive 2002/49/EC of the European Parliament and of the Council of June 25, 2002 on the assessment and management of ambient noise.
- Directive (EU) 2015/996/EU of the Commission of 19 May 2015 establishing common methods of noise assessment.
- Directive (EU) 2020/367 amends Annex III to Directive 2002/49/EC of the European Parliament and of the Council.

2.4.3. Methods for reducing/combating noise

An essential role, in terms of the degree of general atmospheric pollution, but also in terms **of the degree of noise pollution**, **is played by human activities**. It is necessary to determine the values of atmospheric pollutants and the sound level in various areas with specific equipment, according to the profile standards. Concrete measures can be identified for environmental pollutants and the development of an optimal legal framework **[51 - 52].**

C H A P T E R 3

PROPERTIES OF COMPOSITE MATERIALS

3.1. Overview

3.1.1. History of composite materials

"Composite materials are obtained by mixing two or more distinct components. It results in final materials with superior properties to the initial ones" **[2].**

Composite materials appeared in the context of the need to replace existing basic materials: ferrous or non-ferrous, materials that do not have the best performance characteristics in terms of: methods of obtaining and processing, areas of use, costs or masses. These materials present anisotropic properties, and through the method of obtaining and processing, they allow the exploitation of the best characteristics possessed by the initial materials from which they are produced **[3].**

3.2. Composition of composite materials

3.2.1. Matrix of composite materials

The "matrix" is identified among the components of composite materials. This is a component that has an important role in obtaining and characterizing composite materials and at the same time influences the properties of composite materials through its nature and structure.

3.2.2. Reinforcements of composite materials

Another component of composite materials is represented by reinforcement. This, like the matrix, has an important role in obtaining composite materials, as it ensures the reinforcement of the matrix. Reinforcements are classified in the literature into particles and fibers **[12].**

3.3 Acoustics of composite materials

Composite materials represent a new source of materials. These materials are obtained artificially, by mixing at least two constituents and have superior properties to existing ones.

3.3.1. The mechanical properties of composite materials

Composite materials have the following mechanical properties **[16]: resistance** to external forces; **elasticity** - deformation under the action of external forces and return to the original form when they no longer act; **hardness** - the property of resisting the penetration of a foreign body on the external surface.

3.3.2. The physical properties of composite materials

Composite materials have the following physical properties **[16]: material density, thermal conductivity, color, expansion, corrosion resistance**.

3.3.3. The acoustic and thermal properties of composite materials

3.3.3.1. Acoustic properties

Acoustic properties are determined by sound absorption. In order for composite materials to have sound-absorbing properties, the degree of absorption must be as close as possible to unity over a wide frequency range.

3.3.3.2. Thermal properties

The analysis of the thermal insulation behavior of the biocomposite boards carried out in various scientific experiments led to the obtaining of increased values for the thermal resistance and a value of the specific global coefficient of thermal insulation lower than the standardized global coefficient of thermal insulation **[31 - 33].**

C H A P T E R 4

USUAL OPINIONS REGARDING THE EVALUATION OF THE MAXIMUM STRESS CAPABLE OF TAKING UP BY COMPOSITE MATERIALS

4. 1. Introduction

Usual human life has permanently conditioned the finding of favorable consumer goods, which not infrequently impose a high degree of complexity, in various working conditions. This cannot be achieved without the design of high-performance industrial equipment, from the point of view of processing raw materials, in often difficult conditions from the point of view of chemical, mechanical and thermal attack, single or combined.

Classic, natural materials, limited in quantity or for the manufacture of which a high consumption of energy is required, are increasingly being replaced by composite materials. Thus, these materials were called **"composite materials", "materials of the future", "second generation materials"**, respectively **"third generation materials".** It should be noted that such materials have a structure in which the components retain their identities, even after the formation process.

4. 2. Composites reinforced with long fibers

4. 2. 1. Matrices of materials with maximum elongations lower than those of the fibers (polymeric or metallic matrix)

In the following, the hypothesis is accepted that both components of the composite have the same elastic deformation (in the case of the existence of an excellent contact between the matrix material and the fibers).

In this grouping there are refractory composites whose destruction is directly influenced by the elongation of the matrix material. For fiber to matrix contact, equality can be used **[56, 57, 68, 71]:**

$$\left(\sigma_{f\,m}\right)_M = E_f \cdot \left(\varepsilon_{t\,m}\right)_M , \tag{4.1}$$

in which the admissible tensile strength of the fibers, the maximum specific deformation of the matrix material, respectively the longitudinal modulus of elasticity of the fiber material are involved.

The paper **[45],** referring to concrete structures reinforced with steel wires, indicates the following relationship for the evaluation of the breaking strength:

$$\sigma_{c\,r} = A \cdot \sigma_m \cdot \left(1 - p_{v\,f}\right) + B \cdot \sigma_f \cdot \left(l_f / d_f\right), \tag{4.2}$$

which can be used for comparison with the minimum strength, when the cement deterioration begins:

$$\left(\sigma_{c\,r}\right)_m = A \cdot \sigma_{m\,r} \cdot \left(1 - p_{v\,f}\right) + B \cdot \sigma_f \cdot \left(l_f / d_f\right), \tag{4.3}$$

respectively the maximum resistance, in which case all the metal wires in the content break:

$$\left(\sigma_{c\,r}\right)_M = A \cdot \sigma_{m\,r} \cdot \left(1 - p_{v\,f}\right) + B \cdot \sigma_{f\,r} \cdot \left(l_f / d_f\right). \tag{4.4}$$

Analyzing the structure of the previous expressions, it is found that the best composite is the one with fibers whose longitudinal modulus of elasticity has the highest value.

4. 2. 2. The maximum load allowed for tensile stress in a certain direction relative to the orientation of the long fibers

Breaking strength $\left(\sigma_c^\theta\right)_{x\,max}$, for some direction θ , related to the fiber orientation, can be evaluated with the relation **[9, 16, 59, 60, 68]:**

$$\left(\sigma_c^\theta\right)_{x\,max} = \frac{1}{\dfrac{(cos\,\theta)^4}{(\sigma_c)_{x\,max}} + \dfrac{(sin\,\theta)^4}{(\sigma_c)_{y\,max}} + (cos\,\theta)^2 \cdot (sin\,\theta)^2 \cdot \left[\dfrac{1}{\tau_{f\,R}^2} + \dfrac{1}{(\sigma_c)_{x\,max}^2}\right]} \quad \textbf{(4.9)}$$

in which the orientation of the fibers, the direction perpendicular to the fibers and the shearing stress in the plane of the fibers are located.

4. 2. 3. The maximum permissible tensile load in a direction perpendicular to the fibers

Stress/yield strength of the composite $\left(\sigma_c^{tr}\right)_{x\,M}$, the fibers and the matrix having a linear behavior, can be established with equality **[1, 6, 12, 68]:**

$$\left(\sigma_c^{tr}\right)_{x\,M} = \left(\sigma_m\right)_{el} \cdot \left[\left(E_c\right)_{tr} / E_m\right] \cdot \left(1 - \sqrt[3]{p_{vf}}\right). \quad \textbf{(4.10)}$$

Specific elongation of the composite $\left(\varepsilon_c\right)_{tr}$, along a direction perpendicular to that of the fibers, can be calculated with the formula **[6, 43, 68]**:

$$\left(\varepsilon_c\right)_{tr} = \varepsilon_m \cdot \left(1 - \sqrt[3]{p_{vf}}\right). \quad \textbf{(4.11)}$$

The papers **[12, 62, 68]** presents the following calculation relationship for the mentioned request case:

$$\left(\sigma_c\right)_{tr} = \left[1 - \left(\sqrt{p_{vf}} - p_{vf}\right) \cdot \left(1 - E_m / E_2\right)\right] \cdot \sigma_{mt}. \quad \textbf{(4.12)}$$

4.2.4. The shape stability of the composite under compression along the fibers

By compressing the composite, the component fibers can deform **[63, 68],** according to one or the other of the two representative ways **(Fig. 4. 1)**. Some fibers resist very little to such a request (example is Kevlar fibers).

The first mode of buckling **(Fig. 4. 1.)** can occur for a volumetric percentage of reinforcement lower than 30%, in which case the matrix resists the tension-compression stress. In the second mode of buckling, the matrix has a higher volumetric percentage of reinforcement, in which case it resists shearing **[1, 6, 16].** The justification, for each structure, is given by the experimental results undertaken **[6, 9, 68].**

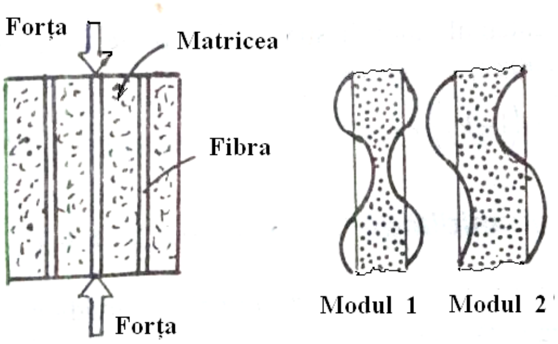


Fig. 4. 1. Buckling modes of the long fibers of the composite **[1, 6, 17, 68]**

For a **compressive stress of a composite reinforced with long fibers**, the yield stress evaluation for this case can be evaluated with the expression (**Fig. 4. 1** – Mode 1 of deformation) **[17, 23, 29, 64, 65, 68]:**

$$\left(\sigma_c\right)_{el}^{f} = 1{,}155 \cdot p_{vf} \cdot \sqrt{p_{vf} \cdot E_f \cdot E_m \Big/ \left(1 - p_{vf}\right)}\ , \qquad \textbf{(4.13)}$$

attributed to ***Rosen W. B.*** **[23, 64]** and, independently, to ***Scheuerch H.*** **[23].**

For mode 2 of deformation - **Fig. 4. 1**, the papers **[17, 23, 68]** propose the expression:

$$\left(\sigma_c\right)_{el}^{f} = G_m \Big/ \left(1 - p_{vf}\right), \qquad \textbf{(4.15)}$$

4. 2. 5. The limit of elasticity in compression in the direction perpendicular to that of the fibers

The papers **[29, 61, 68]** indicate the following relation for calculating the stress/transverse compressive strength for unidirectional fiber reinforced composite:

$$\left(\sigma_c\right)_{com} = \left[1 - \left(\sqrt{p_{vf}} - p_{vf}\right) \cdot \left(1 - E_m / E_2\right)\right] \cdot \sigma_{mc}\ . \qquad \textbf{(4.21)}$$

Similar to the previous expression, can be used for shear stress the following expression **[29]:**

$$\tau_c^{com} = \left[1 - \left(\sqrt{p_{vf}} - p_{vf}\right) \cdot \left(1 - E_m / E_2\right)\right] \cdot \tau_{mc}\ , \qquad \textbf{(4.22)}$$

in which they are present τ_c^{com}, τ_{mc} – shear stresses for the composite and for the matrix material.

The paper **[6]** presents the equality below for the evaluation of the shear stress in plane 1 – 2, limit, considering the shear stress of the fibers and the matrix, respectively the volumetric percentages contained in the composite:

$$\left(\tau_{12}\right)_{lim} = \tau_f \cdot p_{vf} + \tau_m \cdot p_{vm}\ . \qquad \textbf{(4.23)}$$

4. 2. 6. Composite resistance to transverse stretching, transverse compression and fiber shear

For such demands, the stresses induced in the matrix and in the fibers are equivalent **[6]** with the observation that the manufacturing technology strictly respects the imposed requirements. It is obvious that the properties of the fiber-reinforced composite, under the action of such stresses, depend on the limit values, on the mechanical resistance of the matrix material. It should not be overlooked that when stressing the transverse stretching of the fibers, the allowable stresses are higher than those corresponding to the material of the matrix **[6].**

4. 3. Composites reinforced with chopped fibers or particles

4. 3. 1. Tensile strength of composites reinforced with chopped fibers

For a composite with dispersed filler/reinforcement, the stress/tensile strength can be calculated with the relation **[15, 49, 77, 82]:**

$$\sigma_{t\,c} = 2\cdot\sigma_{t\,f}\cdot p_{v\,f}\cdot\left(2 - l_{c\,f}/\,l_{f}\right) + \sigma_{t\,m}\cdot\left(1 - p_{v\,f}\right), \qquad \textbf{(4.25)}$$

The paper **[79]** offers the following expression for the tension/tensile strength of discontinuous fibers, along their length (***Cox H. L.*** – 1952):

$$\sigma_{f} = E_{f}\cdot\varepsilon_{1}\cdot\left\{1 - ch\left[\beta\cdot\left(l_{f}/2 - x\right)\right]/\,ch\left(\beta\cdot l_{f}/2\right)\right\}, \qquad \textbf{(4.27)}$$

4. 3. 2. Mechanical strength of composites with particles

The critical mechanical stress/strength is approximately equal to the flow resistance of the material which, in turn, depends on the degree of dispersion of the secondary phase ("minority phase" **[55, 82]**). The relationship between the volumetric participation of the (ceramic) particles $p_{v\,p}$, the radius (possibly equivalent) r and the distance between them is of the form **[15, 82, 83]:**

$$\lambda = r\cdot\sqrt[3]{4{,}19/\,p_{v\,p}}\,. \qquad \textbf{(4.44)}$$

The shear strength of the composite $\tau_{r\,c}$ can be expressed with the relation **[15, 82, 83]**:

$$\tau_{r\,c} = 3\cdot\tau_{p}\cdot\left(p_{v\,p}\right)^{n}, \qquad \textbf{(4.45)}$$

Considering the structure of a composite with particles, the paper **[84],** for such weakly bonded elements (reduced contact between particles and matrix), presents the relationship (***Danusso F., Tieghi G.*** - 1986; ***Levita G., Marchetti A., Lazzeri A.*** – 1989):

$$\sigma_{t\,c} = \sigma_{m}\cdot\left(1 - p_{v\,p}\right), \qquad \textbf{(4.46)}$$

which shows a decrease in the bearing capacity of the composite, along with the increase in the particle content. The argument is that the active areas in the matrix decrease with the increase in the number of particles. In the same vein, by introducing the effect of the shape of the particles, as well as their arrangement, through the presence of the coefficients a şi b and the previous equality changes accordingly (***Nicolais L., Narkis M., Nicodemo L.*** - 1971, 1974) **[84]:**

$$\sigma^{\bullet}_{t\,c} = \sigma_{m}\cdot\left[1 - a\cdot\left(p_{v\,p}\right)^{b}\right], \qquad \textbf{(4.47)}$$

developed by Bigg D. M. (1987), by introducing the coefficients c şi d , with values chosen corresponding to the practical case (for a better prediction of the strength of the composite):

$$\sigma^{\bullet}_{t\,c} = \sigma_{m}\cdot\left[1 - a\cdot\left(p_{v\,p}\right)^{b} + c\cdot\left(p_{v\,p}\right)^{d}\right]. \qquad \textbf{(4.48)}$$

Also in the mentioned work, other relations are given for the evaluation of the request state from a composite with particles **(Table 4. 1.).**

4. 3. 3. Mechanical strength of composites with whiskers/filaments

According to the paper **[85],** in the case of composites that contain as filler (in some situations with the role of increased hardness, leading to the use of composites in the production of grinding tools, for example) in the form of filaments, their resistance to breaking is positively influenced , as shown by the expression:

$$\sigma_{rc} = \sigma_f \cdot \sqrt{\left\{ p_{vf} \cdot r \Big/ \left[B \cdot \left(1 - \nu_f^2 \right) \right] \right\} \cdot \left(E_c / E_f \right) \cdot \left(e_m / e_f \right)}, \qquad \textbf{(4.61)}$$

The results obtained through experimentation, illustrated by articles or doctoral theses, can bring certainties for practical uses and in the case of structures accepted for sound or thermal insulation. In another way, the stress states developed in composite plates with chopped fibers or with particles embedded in the structure of various industrial equipment can be evaluated, depending on the support systems, to find out the limit states, admissible **[75, 76, 86, 87].**

C H A P T E R 5

COMPOSITE MATERIALS IN THE CONTEXT OF CLIMATE CHANGE

5.1. Advantages and disadvantages of composite materials

Composite materials are obtained by a process of mixing at least two different materials. Through this process, materials with physical, mechanical and chemical characteristics superior to those possessed individually by the materials in the composite structure are obtained **[1].**

Thus, composite materials **present a number of advantages**, as follows **[9, 10]:**

- shows resistance to corrosion and oxidation;
- high vibration damping capacity;
- low energy consumption;
- small volumetric mass relative to the mass of metals;
- durability;
- large-scale use, they can be used in different industrial branches;
- small expansion coefficient compared to metals;
- high shock resistance;
- high temperature resistance;
- increased safety in operation.

Although they have many advantages, composite materials also have disadvantages as follows **[9]:**

- in general, composite materials show a linear behavior, until breaking;
- the process of converting thermoset composite materials into the raw material from which they were obtained is a difficult process;
- the recycling process is also a difficult one, depending on the method chosen, certain materials can be lost;
- increased degree of flammability.

5.2. Fields of use of composite materials

Due to the superior properties possessed by composite materials, they can be used in various fields as follows **[11 - 17]: motor vehicle construction, aerospace, shipbuilding, construction, medical, transport, telecommunications and electronics, sports**.

5.3. Recycling of composite materials

For the **recycling and reuse of composite materials**, **numerous methods are used** globally, including **[18]:**

- A method of recycling waste from reinforced composite materials consists in shredding them, in sizes of $2 - 5\ mm^2$.
- Another method of recycling waste from composite materials consists in treating them at high temperatures, until thermal decomposition, respectively pyrolysis. The material obtained from recycling composite materials using this method is a fine powder that can be used to make other composite materials.
- Another method of recycling waste from composite materials is represented by catalytic conversion. This method consists in mechanically shredding the waste until it becomes fluid, then it is mixed with the catalyst at high pressure and temperature. Through this waste treatment method, carbon fibers with properties similar to those possessed by the original fibers can be obtained.
- Another method of recycling waste from composite materials is represented by incineration.
- By recycling pre-impregnated and laminated composite waste, various reinforcing fibers can be recovered, respectively: glass, Kevlar or carbon fibers. The recovery of these fibers is important because they represent a danger to the environment, as they have a long absorption period and at the same time these fibers have a high cost.

The recycling of waste from composite materials is a topic of current interest. Numerous institutes and universities are making efforts to create an environment conducive to technological innovation in order to research and identify optimal recycling methods **[19].**

5.4. Environmental effects on composite materials

The external environment of composite materials directly influences the properties, structure and processing of composite materials. Among the components of the external environment that have an influence on composite materials are the following **[20]: corrosion and temperature.**

The properties possessed by composite materials are also influenced by factors associated with the environment, such as **[22]**:

- **Exposure of composite materials to operative or ambient light.**
- **The light intensity to which the composite materials are subjected**.

Composite materials are influenced by the environment, more precisely by the actions exerted by environmental factors. These actions can produce numerous damages to composite materials, such as: fiber breakage, matrix damage by cracking or fissuring, detachment of fibers from the matrix. **[23]**.

5.5. Effects of composite materials on the environment

Composite materials contribute to reducing the amount of waste, with a positive effect on the environment. For example, composite wood has a positive impact on the environment, as its reuse in the form of composite material leads to saving forests, reducing the amount of noxes emitted by the production process, and at the same time represents a long-term solution due to its durability, but also a increased degree of resistance to exposure to light, which means that the composite wood does not change its color or structure through prolonged exposure to the sun **[26]**.

C H A P T E R 6

EXPERIMENTAL RESEARCH ON THE OBTAINING OF COMPOSITE PANELS WITH SOUND-ABSORBING PROPERTIES

6. 1. Introduction

World economic development, not always well coordinated, has also led to some imbalances that nature has to deal with. In this sense, climate change has a major impact on the environment and on socio-economic conditions **[1].**

It is necessary to pay more attention to composite materials based on natural or vegetable fibers due to the fact that their reliability has been proven over time and, also, due to the fact that they come from renewable sources and can be placed in different types of mixtures **[4, 48, 72, 85, 103, 122, 125, 130].**

The purpose of this experimental research is to obtain composite materials from waste and to determine the sound-absorbing properties possessed by them, respectively the determination of: the absorption coefficient, the reflection coefficient and the impedance ratio. Implicitly, it is desired to identify solutions to reduce the amount of existing waste globally and the degree of noise pollution. The sound-absorbing panels obtained are intended for use in various industries to reduce noise intensity or for decorative and sound-absorbing purposes in crowded areas such as cinemas, shopping malls and spas **[11, 12, 73, 74, 102].**

Considering the problems generated by the high noise level, it can be said that the discovery of new composite materials with sound absorbing properties is a priority for the field of research and development **[17, 18].**

6. 2. 1. Calculation relations regarding some characteristics of acoustics

6. 2. 1. 3. Specific acoustic impedance

It represents the resistance of the medium to sound propagation. It is denoted by Z (X) and is expressed by the ratio between the value of the specific acoustic pressure p (x) and the value of the velocity of the particle v (x) ($Z(X) = p_x / v_x$ - directed towards the inside of the sample), in a point x of the acoustic system.

6. 2. 1. 4. Wave propagation in solid materials

Wave propagation takes place in a transverse or longitudinal medium (molecules transmit their energy to neighboring molecules, manifesting a series of alternative compressions and extensions) **[40, 42, 44 - 46].**

a) Longitudinal wave speed

The characteristic velocity of longitudinal waves c_l is presented in the form (Newton's I. formula***;*** **n. 1643 - d. 1727***)* **[47, 117]:**

$$c_l = \sqrt{E / \rho_0}\,, \qquad \textbf{(6. 4)}$$

ρ_0 representing the density of the material.

b) Speed of transverse waves [40, 84, 90, 91, 92]

In this case the propagation speed results in the form:

$$c_t = \sqrt{G/\rho_0}; \qquad 0,5 \cdot E/(\mu + 1). \qquad \textbf{(6. 6)}$$

6. 2. 1. 6. Acoustic intensity

The acoustic intensity I is the average value of the energy flow, related to the unit of area or to the unit of time **[35, 44, 47, 48]:**

$$I = \frac{d\bar{\varphi}_w}{dS} = \bar{E} \cdot c = \frac{p_M^2}{2 \cdot \rho_0 \cdot c^2}, \qquad [\mathrm{W/m^2}] \qquad \textbf{(6. 15)}$$

c or v meaning the displacement of the wavefront per unit time.

Depending on the **maximum pressure** (p_M), the acoustic intensity has the expression **[35]:**

$$I = 0,5 \cdot \frac{p_M^2}{\rho \cdot c}, \qquad \textbf{(6. 17)}$$

respectively:

$$I = 0,5 \cdot v_M^2 \cdot \rho \cdot V, \qquad \textbf{(6. 18)}$$

in which the speed of the material particles in the structure of the environment intervenes.

6. 2. 1. 7. Determination of the (weighted) acoustic absorption coefficient

6. 2. 1. 7. 1. Theoretical evaluation

The (weighted) acoustic absorption coefficient is used to assess a material's ability to absorb sound **[30, 31, 48].**

When a sound wave reaches a material, its energy is divided into three parts. The energy reaching the material is incident (E_i), part of this energy is reflected (E_r) while part of the energy is absorbed/dissipated (E_a) in the material. The rest of the energy is transmitted (E_t) to the other side of the material, as shown in **Fig. 6. 1. [115, 119, 120]** :

$$E_i = E_r + E_a + E_t. \qquad \textbf{(6. 20)}$$

The (weighted) acoustic absorption coefficient can be evaluated with the relation **[35]:**

$$\alpha = \frac{E_i - E_r}{E_i} = \frac{E_a + E_t}{E_i}, \qquad \textbf{(6. 21)}$$

with values between 0 and 1.0.

The (weighted) acoustic absorption coefficient takes values between 0 (the sound wave is reflected by the encountered surface) and 1.0 (all the energy is absorbed or transmitted further).

6. 2. 1. 7. 2. Experimental determination

To characterize the sound-absorbing properties of a material, the measurement methods used are **[35, 43]:**

- Reverberation chamber method.
- Impedance tube method.

The impedance tube method (**Fig. 6. 2**) includes two standard variants used to measure the acoustic absorption coefficient at normal incidence: stationary ratio wave method **[31, 52]** and the transfer function method **[30, 31, 33, 61]**.

The transfer function method involves the use of an acoustic interferometer, two microphone positions and a digital frequency analysis system. The method is limited to parametric studies at normal incidence, requiring samples from the object under test, of the same size, with the cross section of the acoustic interferometer. The usable frequency range depends on the length of the tube and the distance between the microphone positions **[54]**.

The method is based on the fact that, in this case, the level of sound absorption can be determined from the transfer function measured between two positions of the microphone in front of the material under test (**Fig. 6. 3).**

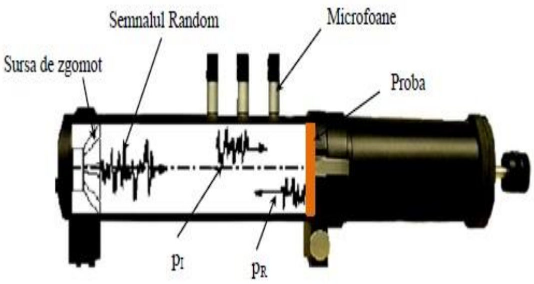


Fig. 6. 2. Introducing the Impendance tube with two microphones **[35, 53]**

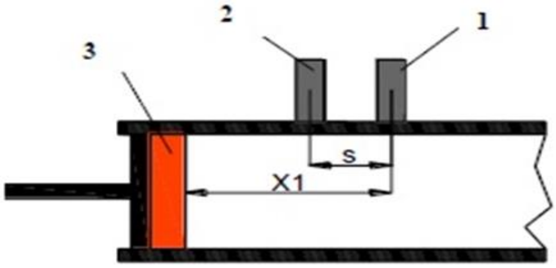


Fig. 6. 3. The position of the microphones relative to the sample **[35, 43]**

<u>Note</u>: To determine the reflection coefficient r, the admittance $G = 1/Z$ and the impedance Z the measured values for the acoustic wavelength λ_0 and the distance $x_{min,1}$ of the first acoustic pressure minimum from the plane of reference $x = 0$ are taken into account.

<u>Note</u>: Therefore, the (weighted) sound absorption coefficient is defined by the ratio of the sound energy absorbed E_a by the medium through which the wave passes to the energy of the incident wave E_i **[32]**:

$$\alpha = E_a / E_i \,. \qquad \textbf{(6. 45)}$$

For the composites obtained during the experiment, subjected to the Kundt Tube **[68]** in order to determine the sound absorption coefficient in the frequency range: 0 Hz- 3200 Hz, the average noise reduction coefficient can also be calculated, for frequencies 800 Hz, 2000 Hz and 3200 Hz using the following calculation relationship:

$$NRC = (\alpha_1 + \alpha_2 + \alpha_3) = \alpha_m \qquad \textbf{(6. 46)}$$

6. 2. 1. 11. Reduction of the overall noise level

It is calculated with the relationship **[35, 56 – 58**]:

$$\Delta\ L = 10 \cdot log\ \left(A / A_0 \right), \qquad \textbf{(6. 55)}$$

where A represents the area of the equivalent acoustic absorption surface, after applying the acoustic treatment; A_0 - the area of the equivalent acoustic absorption surface, without acoustic treatment.

6.2.2. The methodology for making the composites obtained during the experiment

In the present experiment, 15 composite materials with a diameter of 63 mm and different thickness dimensions were made: 6 pieces with a thickness of 20 mm, 6 pieces with a thickness of 40 mm and 3 pieces with a thickness of 60 mm. These samples **(Fig. 6. 11)** were obtained at room temperature, in an interval of about 48 hours, by mixing one, two or three base materials with binder and water.

Fig. 6. 11. Samples obtained during the experiment

6.4. Determination of the sound-absorbing properties presented by the composites obtained during the experiment

6.4.1. Presentation of the acoustic system used to determine the absorption coefficient, the reflection coefficient and the sound impedance ratio for the composites obtained in the experiment

To determine the sound absorption coefficient, the reflection coefficient and the impedance ratio for the obtained composite materials, the Kundt impedance tube method **(Fig. 6. 12),** is used, according to a standardized method **[30].**

The values of these coefficients were determined for the width of the frequency band 0÷3200 Hz. Data from the experiment were acquired and processed by Bruël&Kjær PULSE Platform type 7758 **[31].**

6.4.2. Presentation of the obtained experimental results and their interpretation

6.4.2.1. Experimental results obtained

Sample $\mathbf{P_1^{20}}$ obtained, following experimental determinations, an absorption coefficient$=\mathbf{0,95}$, which places the obtained composite material in Class A of acoustic absorption. The absorption coefficient varies between 400 Hz ... 2000 Hz, at which point it starts to decrease **(Fig. 6. 13)**.

Sample $\mathbf{P_2^{20}}$ obtained, following experimental determinations, an absorption coefficient $\boldsymbol{\alpha = 0,55}$, which places the obtained composite material in Class D of acoustic absorption. The absorption coefficient shows a progressive increase from 400 Hz to 1200 Hz, at which point it starts to decrease. From 2000 Hz the coefficient shows an increase again up to 2800 Hz, but the threshold reached does not exceed 0.45 **(Fig. 6. 14)**.

Sample $\mathbf{P_3^{20}}$ obtained, following experimental determinations, an absorption coefficient $\boldsymbol{\alpha = 1}$ which places the obtained composite material in Class A of acoustic absorption. The absorption coefficient varies between 400 Hz and 3000 Hz, at which point it starts to decrease **(Fig. 6. 15)**.

Sample $\mathbf{P_4^{20}}$ obtained, following experimental determinations, an absorption coefficient $\boldsymbol{\alpha = 0,5}$, which places the obtained composite material in Class D of acoustic absorption. The absorption coefficient shows a variation between 400 Hz ... 1600 Hz, at which point it starts to decrease, but the threshold reached does not exceed 0.35. From 2000 Hz the coefficient shows an increase again until 2800 Hz, at which time the absorption coefficient reaches the threshold of α = 0.5, then it starts to decrease **(Fig. 6. 16)**.

Sample $\mathbf{P_5^{20}}$ obtained, following experimental determinations, an absorption coefficient of approximately $\boldsymbol{\alpha = 0,85}$ which places the obtained composite material in Class B of acoustic absorption. The absorption coefficient varies between 400 Hz and 2000 Hz, at which point it starts to decrease **(Fig. 6. 17)**.

Sample $\mathbf{P_6^{20}}$ obtained, following experimental determinations, an absorption coefficient above $\boldsymbol{\alpha = 0,5}$, which places the obtained composite material in Class D of acoustic absorption. The absorption coefficient varies between 400 Hz and 1200 Hz, at which point it starts to decrease **(Fig. 6. 18)**.

For sample $\mathbf{P_1^{40}}$ an absorption coefficient $\boldsymbol{\alpha = 0,85}$, was obtained following experimental determinations, which places the composite material obtained in Class B of acoustic absorption. The absorption coefficient varies between 800 Hz and 1300 Hz, at which point it starts to decrease **(Fig. 6. 19)**.

Sample $\mathbf{P_2^{40}}$ obtained, following experimental determinations, an absorption coefficient $\boldsymbol{\alpha = 1}$, which places the obtained composite material in Class A of acoustic absorption. The absorption coefficient shows a progressive increase from 0 Hz to 1000 Hz, at which point it starts to decrease **(Fig. 6. 20)**.

Sample $\mathbf{P_3^{40}}$ obtained, following experimental determinations, an absorption coefficient $\boldsymbol{\alpha = 0,6}$, which places the obtained composite material in Class C of acoustic absorption. The absorption coefficient varies from 2400 Hz to 3200 Hz, at which point it begins to decrease **(Fig. 6. 21)**.

Sample $\mathbf{P_4^{40}}$ obtained, following experimental determinations, an absorption coefficient $\boldsymbol{\alpha = 0,5}$ which places the obtained composite material in Class D of acoustic absorption. The absorption coefficient varies from 400 Hz to 900 Hz, at which point it begins to decrease **(Fig. 6. 22)**.

Sample $\mathbf{P_5^{40}}$ obtained, following experimental determinations, an absorption coefficient $\boldsymbol{\alpha = 0,4}$ which places the obtained composite material in Class D of acoustic absorption. The absorption coefficient changes from 0 Hz to 500 Hz, at which point it starts to decrease **(Fig. 6. 23)**.

Sample $\mathbf{P_6^{40}}$ obtained, following experimental determinations, an absorption coefficient $\boldsymbol{\alpha = 0,3}$ which places the obtained composite material in Class D of acoustic absorption. The absorption coefficient changes from 0 Hz to 400 Hz, at which point it starts to decrease **(Fig. 6. 24)**.

Sample $\mathbf{P_1^{60}}$ obtained, following experimental determinations, an absorption coefficient $\boldsymbol{\alpha = 0,1}$ which places the obtained composite material in the classless category **(Fig. 6. 25)**.

Sample $\mathbf{P_2^{60}}$ obtained, following experimental determinations, an absorption coefficient $\boldsymbol{\alpha = 0,6}$ which places the obtained composite material in Class C of acoustic absorption. The absorption coefficient varies from 0 Hz to 400 Hz, at which point it begins to decrease **(Fig. 6. 26)**.

Sample $\mathbf{P_3^{60}}$ obtained, following experimental determinations, an absorption coefficient $\boldsymbol{\alpha = 0,85}$ which places the obtained composite material in Class B of acoustic absorption. The absorption coefficient varies from 0 Hz to 600 Hz, at which point it starts to decrease **(Fig. 6. 27)**.

6.4.2.2. Interpretation of the obtained results

The degree of acoustic performance presented by the composite materials obtained during the experimental research is directly influenced, both by the thickness of the composite material and by the nature and percentage of the binder used **[132].** In order for composite materials to have sound-absorbing properties, the absorption coefficient must have a value as close as possible to $\alpha = 1$ (value maintained over the widest possible range) **(Fig. 6. 28).**

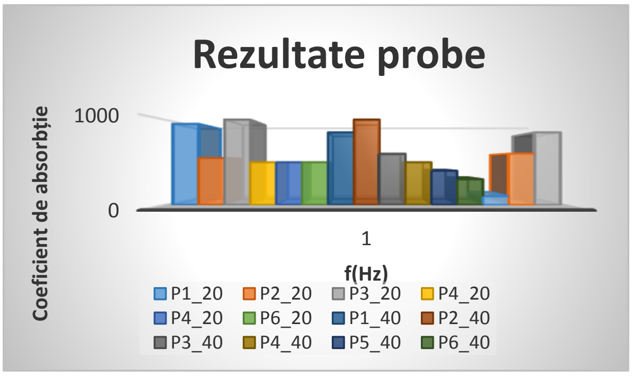


Fig. 6. 28. Interpretation of Samples result (Kundt tube)

Table 6. 4. Absorption class according to absorption coefficient α **[34]**

Acoustic absorption class	α
A	0,90; 0,95; 1,00
B	0,80; 0,85
C	0,60; 0,65; 0,70; 0,75
D	0,30; 0,35; 0,40; 0,45; 0,50; 0,55
E	0,15; 0,20; 0,25
Classless	0,00; 0,05; 0,10

The interpretation of the values of the sound absorption coefficient obtained by the experimental samples is carried out by establishing their belonging to sound absorption classes, according to the table above **(Table 6. 4).**

The experimental test results are illustrated in the graphs below for better comparison **(Fig. 6. 29 - Fig. 6. 31).**

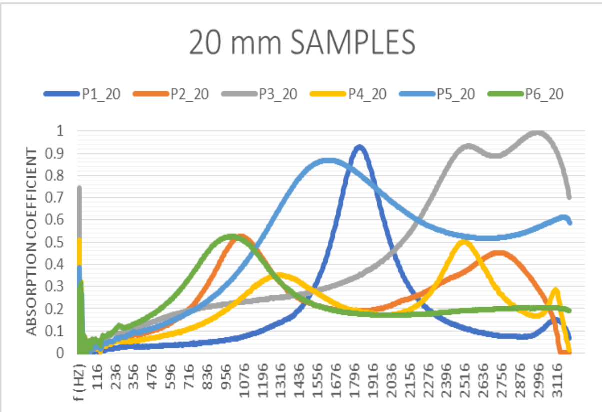


Fig. 6. 29. Results for the 20 mm Samples (Kundt tube)

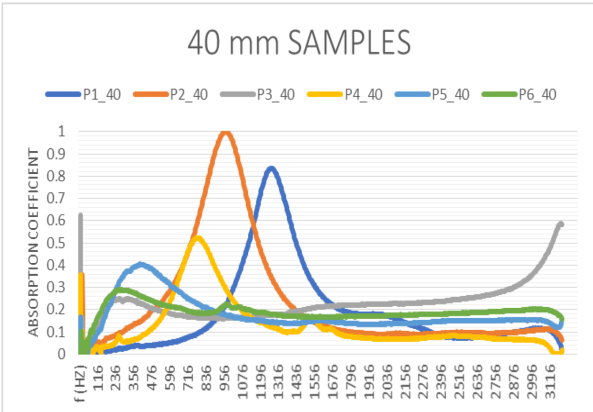


Fig. 6. 30. Results for the 40 mm Samples (Kundt tube)

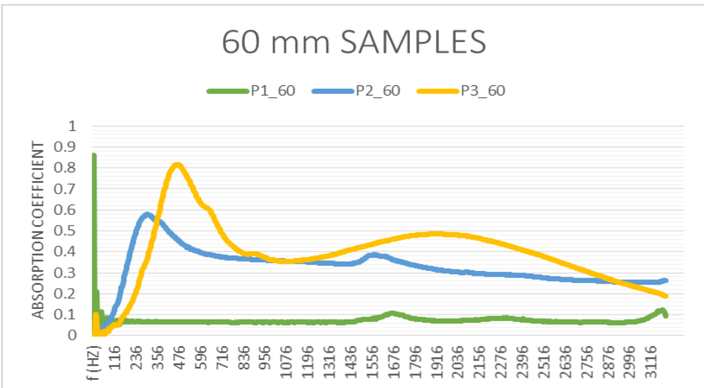


Fig. 6. 31. Results for the 60 mm Samples (Kundt tube)

From the interpretation of the results obtained from the samples, it can be seen that a number of 6 experimental samples belong to absorption classes A and B according to the absorption coefficient α , which results in the fact that these composite materials can be used in the creation of plates for absorption sound in order to protect people in industrial halls, performance halls, for rooms with a high degree of noise. The panels obtained from the experimental samples that belong to absorption classes C and D according to the absorption coefficient α can be used for rooms with a lower degree of noise.

Regarding the reflection coefficient, the experimental samples obtained the following values indicated in the **Figures 6. 32 - 6. 34.**

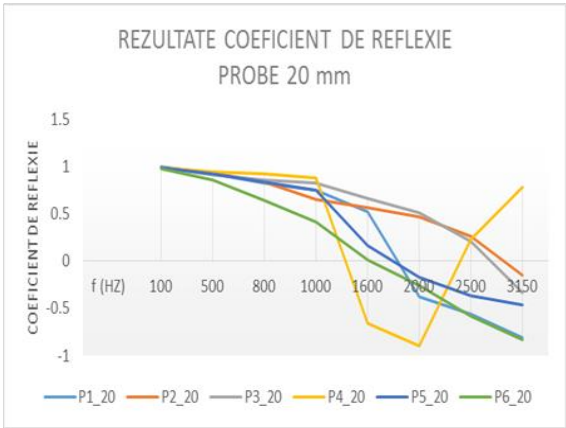


Fig. 6. 32. Results for the 20 mm Samples (reflection coefficient)

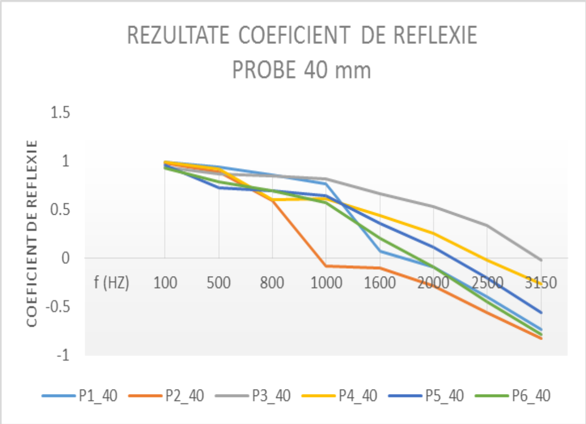


Fig. 6. 33. Results for the 40 mm Samples (reflection coefficient)

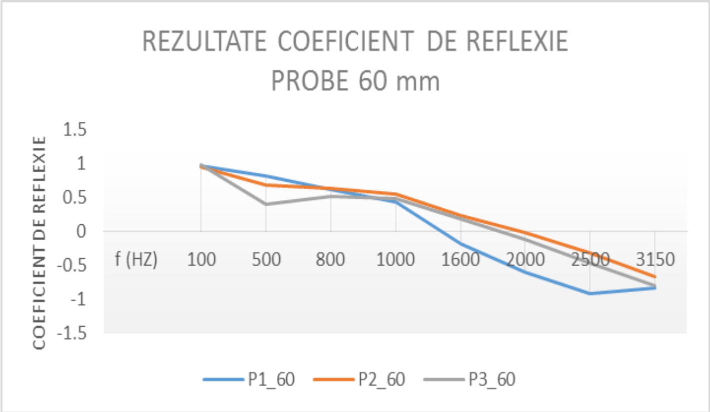


Fig. 6. 34. Results for the 60 mm Samples (reflection coefficient)

As can be seen from the values obtained by the experimental samples, presented in the graphs above, the reflection coefficient shows increased values, located between 0.6 and 1 in the frequency range 100-1000 Hz. Subjected to high frequencies, the experimental samples obtained negative values.

Experimental samples P_4^{20}, P_3^{20}, P_3^{40}, P_1^{40} și P_1^{60} obtained the best values for the reflection coefficient.

Regarding the impedance ratio, the experimental samples obtained the values indicated in **Figures 6. 35 - 6. 37.**

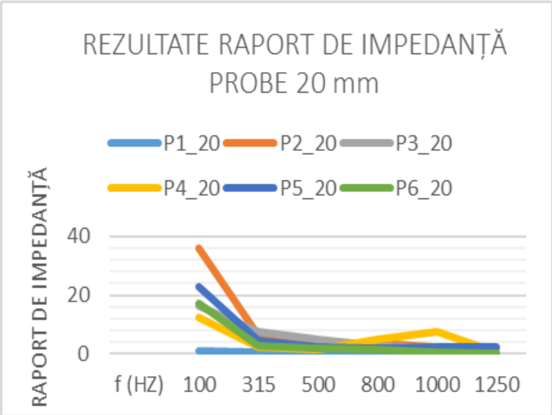


Fig. 6. 35. Results for the 20 mm Samples (impedance ratio)

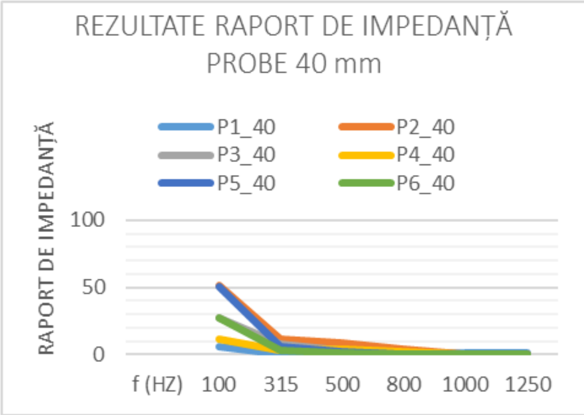


Fig. 6. 36. Results for the 40 mm Samples (impedance ratio)

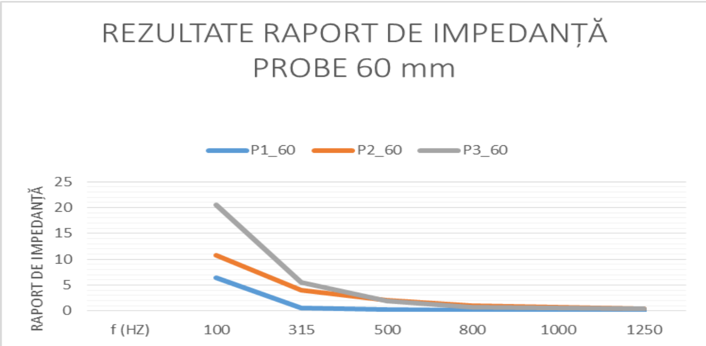


Fig. 6. 37. Results for the 60 mm Samples (impedance ratio)

After processing the data and interpreting the results of the experimental samples, it is found that they obtained an important variation of the impedance ratio in the frequency range 100-1000 Hz.

In the case of exposure to high frequencies, the values obtained by the experimental samples for impedance tend to 0.

Considering the individual positive results obtained by the experimental samples, it can be stated that panels with mechanical and sound-absorbing properties can be made from them and can be used in various fields. At the same time, these results represent an encouragement for the development of research in the field for other composite materials obtained from recycled waste.

6.5. Comparative sound level determinations

6.5.1. Description of the experiment

In the present experiment, the ability of composite structures, made and evaluated in this thesis, to absorb sound was measured. The values obtained by these composite structures were compared with the values obtained by boards made from ligno-cellulosic waste.

Boards from ligno-cellulosic waste, sandwich type (MDF/PS/MDF), assembled in the form of a box) have the following structure:

- wood waste, fine wood powder with formaldehyde resin (MDF) with a thickness of 20 mm;
- thick extruded polystyrene (PS) polymer core of 20 mm;

- transparent glue for film bonding in ultra-adherent thin layer - Polymax/crystal express BISON.

To measure the sound absorption capacity of the experimental samples, they (the samples belonging to classes A and B according to the value of the absorption coefficient) were inserted (one by one, individually) into a side wall of the ligno-cellulosic waste box , according to **Figures 6. 38 – 6. 39:**

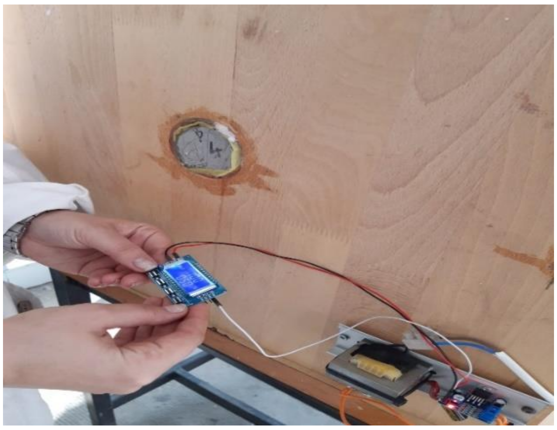
Fig. 6. 38. Creating the hole for the experiment

6. 39. The presentation of the experiment (inserted samples)

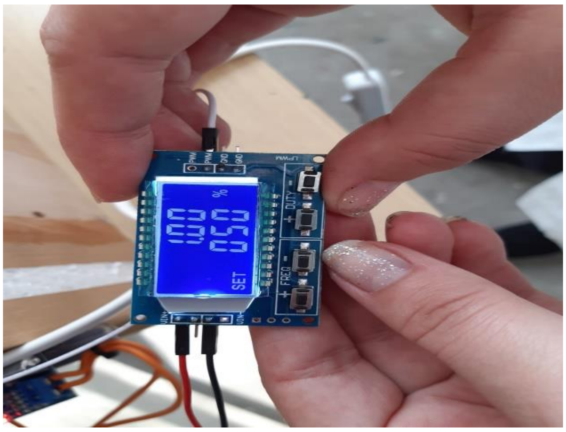
6.5.2. The equipment used

The noise level was measured with the help of the "sonometer" **(Fig. 6. 40)** and the production of sounds was carried out with the help of a sound generating equipment, for the width of the frequency band 0÷1000 Hz **(Fig. 6. 41).**

The equipment consists of a generator (speaker), a luminous dial, buttons for setting the frequency (+, -), load switch, output terminals. It allows the generator (speaker) to be inserted inside the box and the frequency changed from outside the box via the dial with buttons for setting the frequency, as can be seen in **Figure 6. 42.**



6. 41. Equipment used

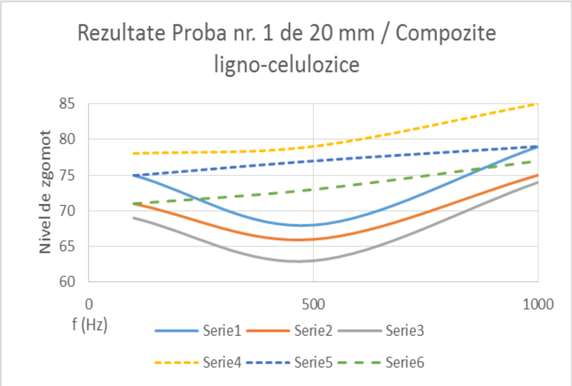


6. 42. Components of the equipment used

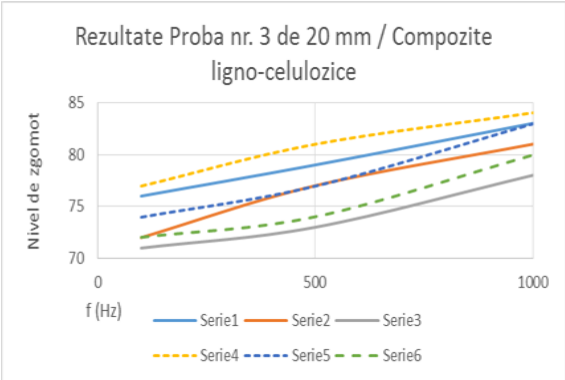
Measurements were made for frequencies of 100 Hz, 500 Hz and 1000 Hz and for distances of 0 m, 1 m and 2 m. Measurements for distances of 1 m / 2 m were made using polypropylene pipes.

6.5.3. Results and interpretation

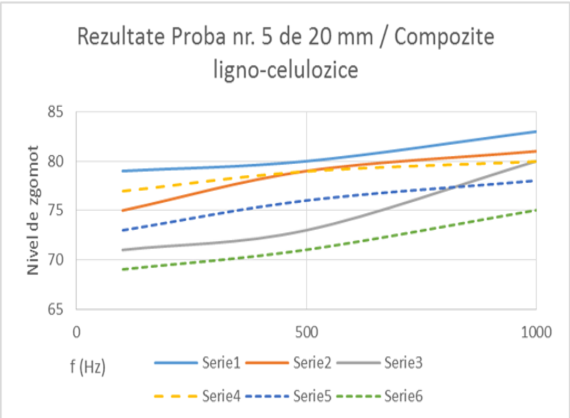
The results obtained from the experimental samples and ligno-cellulosic waste composites are illustrated in the graphs below **(Fig. 6. 43 – 6. 48).** The results of the experimental tests carried out and evaluated in this thesis are represented graphically with continuous lines (series 1-3), and the results obtained for ligno-cellulosic composites are represented graphically with broken lines (series 4-6).



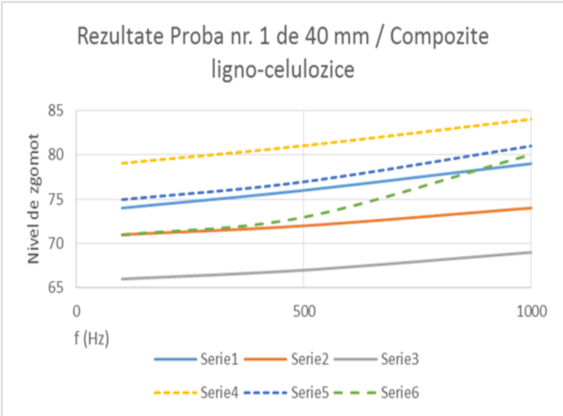
6. 43. Results for $\boldsymbol{P_1^{20}}$ / ligno-cellulosic composites



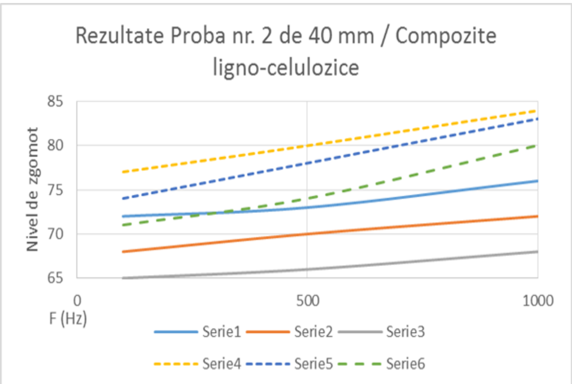
6. 44. Results for $\boldsymbol{P_3^{20}}$ / ligno-cellulosic composites



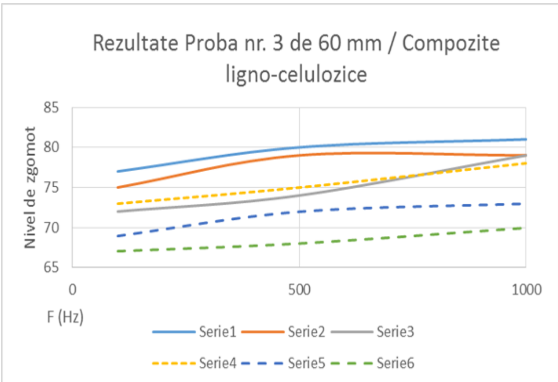
6. 45. Results for $\boldsymbol{P_5^{20}}$ / ligno-cellulosic composites



6. 46. Results for $\boldsymbol{P_1^{40}}$ / ligno-cellulosic composites



6. 47. Results for $\boldsymbol{P_2^{40}}$ / ligno-cellulosic composites



6. 48. Results for $\boldsymbol{P_3^{60}}$ / ligno-cellulosic composites

From the interpretation of the results, it follows that samples $\boldsymbol{P_1^{20}}$, $\boldsymbol{P_3^{20}}$, $\boldsymbol{P_1^{40}}$ and $\boldsymbol{P_2^{40}}$ obtained better values in terms of noise level, compared to the values obtained by the ligno-cellulosic composites. Samples $\boldsymbol{P_5^{20}}$ and $\boldsymbol{P_3^{60}}$ obtained weaker values compared to the values obtained by the ligno-cellulosic composites for the sound level.

Note: It is highlighted that the size and thickness of the plates have an influence on the vibrations and implicitly, on the sound-absorbing characteristics possessed by the composites made and evaluated in this thesis.

C H A P T E R 7

FINAL CONCLUSIONS, OWN CONTRIBUTIONS AND PERSPECTIVES

7.1. Final conclusions

This doctoral thesis "Research on the mechanical and sound-absorbing characteristics of composite structures reinforced with fibers or particles" presents both theoretical aspects regarding the mechanical and sound-absorbing characteristics of composite structures reinforced with fibers or particles, as well as experimental aspects regarding the methodology to obtain composite structures with sound-absorbing properties, from waste.

Composite materials represent an alternative to existing raw materials that it can replace due to their superior properties **[9-10-cap. 5].** The method of obtaining composite materials is a complex one **[1 - cap. 3].**

Such materials are found in numerous categories, depending on the characteristics they have or their behavior in certain conditions. The mechanical behavior of composite materials is influenced by the properties of each component material and the proportion of the component materials **[8 - cap. 3].**

Due to the superior properties possessed by composite materials, they can be used in various fields as follows **[11 – 17 - cap. 5]:** automotive construction, aerospace, shipbuilding, medical, transport, telecommunications and electronics, sports., etc.

As part of the experimental research, 15 experimental samples were made with different compositions and thicknesses, respectively: 6 pieces with 20 mm, 6 pieces with 40 mm and 3 pieces with 60 mm. These samples, by their nature, biodegradable waste, have the advantage that they can be recycled more easily.

Analyzing the results obtained after determining the values of the sound absorption coefficient for the composite materials obtained during the experiment, it can be stated that of these, especially the 6 experimental samples that belong to absorption classes A and B according to the value of the absorption coefficient $\boldsymbol{\alpha}$ obtained, boards can be made for sound absorption in order to protect people in industrial halls, theaters, for rooms with a high degree of noise. The panels obtained from the experimental samples that belong to absorption classes C and D according to the absorption coefficient $\boldsymbol{\alpha}$ can be used for rooms with a lower degree of noise.

The results obtained through experiments, illustrated by articles or doctoral theses, can bring certainties for practical uses in the case of composite structures for acoustic or thermal insulation **[86, 87 - cap. 4].**

7.2. Own contributions

This thesis contains both existing elements in the specialized literature, as well as new elements, own contributions, harmoniously combined with the aim of fulfilling the proposed objectives.

Among the own contributions to this thesis are the following:

a) **Theoretical character:**

- Studying useful elements for the subject of the thesis, regarding the current state of research, as a starting point for the thesis, from specialized literature: books, courses, scientific articles, doctoral theses, internet sources, etc. The existence of countless bibliographic sources denotes the fact that the subject of this work shows a high degree of interest from researchers around the world.
- Extraction and processing of elements from the specialized literature on composite materials, respectively: history, classification, methods of obtaining, testing methods, possessed characteristics, recycling methods.
- Detailing the physical, mechanical, thermal and sound-absorbing characteristics possessed by the composite materials by presenting the mathematical expressions used according to the category of composite structures analyzed.
- Creation of a chapter on the mechanical characteristics presented by composite materials (maximum mechanical strength of composite structures reinforced with long fibers, with chopped fibers or with particles), taking into account the behavior of the law between the composite matrix and the reinforcing elements, based on the opinions formulated by the researchers from the field.

In conclusion, the first part of the paper presents a history of sound pollution, caused by noise, and the negative impact it has on the environment and population, and at the same time the theoretical data on composite materials, especially the data on their phonic and mechanical characteristics.

b) **Experimental character:**

- The choice of the research direction was made by studying the various existing studies in the specialized literature and, implicitly, comparing the results obtained within these studies with the aim of choosing the most optimal research direction for this doctoral thesis.
- Elaboration of the methodology for making the experimental samples (composite structures) studied in this thesis, respectively: the choice of the categories of waste necessary to obtain the experimental samples; establishing the composition and thickness of the experimental samples: establishing the amount of waste required for each sample, individually, depending on the chosen composition; treatment of waste chosen for making samples (shredding).
- Obtaining experimental samples (composite structures) from the chosen waste, in accordance with the plan developed for carrying out the experiment.
- Determining the sound-absorbing characteristics for the experimental samples, respectively determining the values of the sound absorption coefficient, the reflection coefficient and the impedance ratio for each individual sample.
- Collection of data resulting from the submission of experimental samples made to the Kundt tube.
- The processing of the data obtained in order to create the individual graphic representation, for each individual sample, to highlight the variation curves of the sound absorption coefficient, the impedance ratio and the reflection coefficient according to frequency (0÷3200 Hz).
- Interpreting the results obtained from individual experimental samples and comparing these results by category, according to their thickness and by sound absorption classes according to international legislative provisions according to the results obtained by the sound absorption coefficient.
- Establishing the optimal combinations for making sound-absorbing panels that could be used to protect the environment and people against noise pollution.

- Dissemination of the results obtained during international conferences, in magazines/journals indexed in the international database or indexed by ISI (Institute for Scientific Information).

7.3. Perspectives

The experimental samples (composite structures) made and studied in this thesis obtained positive results following the determinations made, and thus it was scientifically proven that they possess sound-absorbing properties.

Therefore, new research perspectives have opened up in this field, as follows:

- Future study of other recycled waste in order to obtain composite materials with mechanical and physical properties superior to those possessed individually by the original materials.
- Studying the degradation time period for the composite structures made and studied in this thesis.
- Obtaining and studying composite materials of different sizes, thicknesses and compositions, as it has been proven that these characteristics directly influence their properties, in order to determine the sound-absorbing or non-sound-absorbing properties they possess and, respectively, the possibilities of their exploitation.
- Study of composite structures obtained by using different materials as binders.
- Using and studying the behavior of composite materials obtained as soundproofing materials in different rooms.
- Studying the lifetime for the materials obtained in this thesis or the bearing capacity, under the action of different simple, variable or multiple loads.
- Studying the possibilities of recycling these composite materials with the aim of identifying methods that are as friendly to the environment and the health of human society.
- Realization of the optimization of the composite structures obtained by studying the defects presented by them.
- Studying the behavior of composite structures obtained when exposed to thermal shocks or mechanical loads.
- Elaboration of the transposition strategy of the composite materials studied and realized in this thesis, from the project stage, to attestation and commercialization on a large scale.
- The results of this study can be used in the field of noise prediction, respectively for the development of databases according to the provisions of international legislation in this field.

Considering the positive results obtained by the experimental samples, the composite structures made and studied in this thesis, it can be stated that sound-absorbing panels can be obtained from them that can be used in various fields. At the same time, these results represent an encouragement for the development of research in the field, for the creation of composite materials from other types of waste.

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CHAPTER 6

EXPERIMENTAL RESEARCH ON THE OBTAINING OF COMPOSITE PANELS WITH SOUND-ABSORBING PROPERTIES

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