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Acoustic Properties of a New Composite Material Obtained from Feather Flour and Recycled Polypropylene

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Abstract: *Sustainable materials made from recycled materials are an alternative to traditional materials (synthetic ones) and present a lower environmental impact. Due to the fact that natural fibers were successfully used to produce environmentally friendly sound adsorbing materials, biocomposites made from recycled polypropylene (PPR), feathers flour (FF) with / without compatibilizers (C) were obtained and characterized from the point of view of their acoustical behavior. Obtained materials were characterized also from the morphological and compositional point of view by scanning electron microscopy and thermal gravimetric analysis. All tested samples presented sound adsorption properties but the best results were obtained for the biocomposites with FF content of 10%-20%.*

Keywords*: noise pollution, feather flour, recycled polypropylene, wastes, sound absorption coefficient*

1. Introduction

Noise pollution represents an important factor that affects human health, and possible lead to cardiovascular disease, risk of a high blood pressure, lack of cognitive performance of children, etc. [1]. In order to avoid it, a broad range of acoustic materials, applied in various domains, were developed in the last years. Based on their microscopic configurations, acoustic materials were divided in various classes [2]: volume absorber, membrane absorber, porous absorber: granular, fibrous, cellular.

Good sound absorbing properties are determined by parameters such as porosity, density and pores' area. [3] explained incident sound wave phenomenon at the surface of the materials: the air molecules vibrate and loose a part of their energy by converting this into heat. At low frequencies this transformation is isothermal and at high one, the transformation is adiabatic.

Natural fibers were successfully used in manufacturing sound absorbing materials [4] and are completely/partly biodegradable, environmentally friendly and safer for human health. New developments propose the use of natural fibers instead of industrial ones [5].

Polymer materials used as sound insulations present good results because they are weightier than conventional materials made from of stone, wool and glass, and also, they are characterized by low toxicity and controlled properties, but having the disadvantage of being more expensive [6].

In the last years, researchers aimed to develop new better sound absorbing composite materials, using various waste and recycled materials [7,8].

The purpose of this paper is to present acoustic properties of a new material made of feather flour (obtained from chicken feathers) and recycled polypropylene. Chicken feathers, natural materials, are obtained in large quantities as a by-product in the production of chicken meat and a large part of it is ending as waste.

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2. Materials and methods

2.1. Materials

Recycled polypropylene was mixed with feather flour in the proportion between 10 and 50 %. A comprehensive description of preparation method was described in previous works [9]. In order to improve adhesion between composite components, additives were added (32%).

2.2. Composite preparation

For preparation process of the composite material, a steel mold was made with the following characteristics: 5 mm thick steel box with and inner diameter of 63 mm, provided with two 6 mm holes placed at 20 mm from the base.

The obtained granules, using various recipes described in previous work [9], were placed inside the mold until it was filled enough to allow the placement of the lid provided with a uniformity disk. Then, the mold was heated in the oven to 200ºC for up to at 5 min, depending on each recipe composition (the amount of added feather flour influences the viscosity of the mixture).

When the biocomposite material began to flow through the overflow holes of the mold, the mold was removed from the oven and allowed to cool at room temperature.

After cooling, the biocomposite tablet with the desired dimensions was extracted: 63 mm in diameter and 20 mm in height. For easier extraction, the mold was lubricated with a thin layer of WD-40 technical lubricant.

The following recipes were used for preparation of composite materials and are presented in Table 1:

Table 1. Tested composite materials

Sample	**Composites without additives**			
	II-2	II-3	II-4	II-5
PPR	90%	80%	70%	50%
LLDPE	-	-	-	-
Licowax PED 521 GR	-	-	-	-
Vistamax	-	-	-	-
Hostavin N30	-	-	-	-
$CaCO_3$	-	-	-	-
FF	10%	20%	30%	50%
Sample	**Composites with additives**			
	III-6	III-7	III-8	III-9
PPR	58%	48%	32%	12%
LLDPE	10%	10%	12%	12%
Licowax PED 521 GR	2.25%	2.25%	2.7%	2.7%
Vistamax	2.25%	2.25%	2.7%	2.7%
Hostavin N30	0.5%	0.5%	0.6%	0.6%
$CaCO_3$	17%	17%	20%	20%
FF	10%	20%	30%	50%

Note: PPR – recycled polypropylene, FF – feather flour, LDPE – linear low density polyethylene resin, Licowax PED 531 GR – dispersing aid, Vistamax N30 – to improve adhesion and elasticity, Hostavin N30 – light stabilizer, $CaCO_3$ – filling material. All concentrations are massic.

2.3. Methods

2.3.1. Scanning electron microscopy

To examine the morphology of the composite materials, scanning electron microscopy (SEM) images were recorded with a Quanta FEG 250 with STEM and EDX detectors. The Quanta FEG Scanning Electron Microscope produces enlarged images of a variety of specimens, achieving magnifications of over 100 000× providing high resolution imaging in a digital format.

2.3.2. Thermogravimetric analysis

A Netzsch STA PC 409 equipment was used. Working atmosphere was synthetic air, 100 mL/min in alumina crucibles. The heating program was 35-1200°C with a heating speed of 10°C/min.

2.3.3. Sound absorption measurement

The apparatus for determining the absorption coefficient consists of an acoustic interferometer tube (Kundt tube presented below in Figure 1), type 4206-A (medium tube), a five-channel simultaneous signal acquisition system with signal generator - PULSE multi-analyzer type 3560-B-030, two microphones type 4187, a signal amplifier 2716 and an acoustic calibrator type 4231 with adapter DP-0775 for microphones.

The samples were used to measure the sound absorption coefficient at a medium-frequency stage (100 Hz and 3.2 kHz). The impedance tube is straight, with rigid, smooth walls, no pores, no holes or slots (except for those for microphone positions) in the testing section. The impedances tube's walls are heavy and thick because acoustic signal should not produce vibration and there must be no resonances of vibrations in the frequency range of the tube. The sample is mounted at the end of the linear tube.

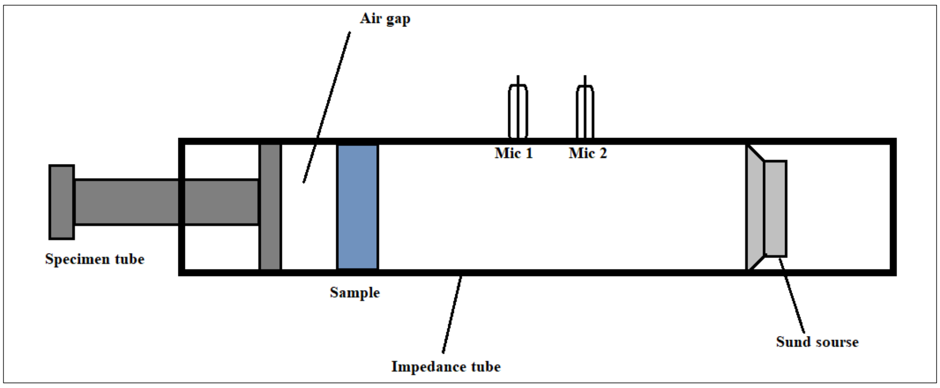


Figure 1. Structure of Kundt tube

3. Results and discussions

3.1. Bio composite morphology

3.1.1 Characterization using scanning electron microscopy

Figure 2 shows the SEM micrographs of composites without additives.

The average size of pores increases as follows: II-4 (84.77 µm), II-3 (187.97 µm), II-2 (234.86 µm), II-1 (356.40 µm). Based on SEM micrographs it was concluded that the average size of pores decreases with the increase of feather flour percentage. Smaller pore size usually suggests better sound absorption coefficient due to the fact that a small size of pores means more collisions with the sound wave, a longer reflection and refraction path and more absorption energy [10].

Figure 3 is presenting the SEM images of composites with additives.

Similar with the results for composite samples without additives, the average pore dimensions decrease with the increase of feather flour percentage. The average size of pores for composites with additives increases in the following order: III-9 (54.22 µm), III-8 (126.48 µm), III-7 (229.30), III-6 (294.37 µm).

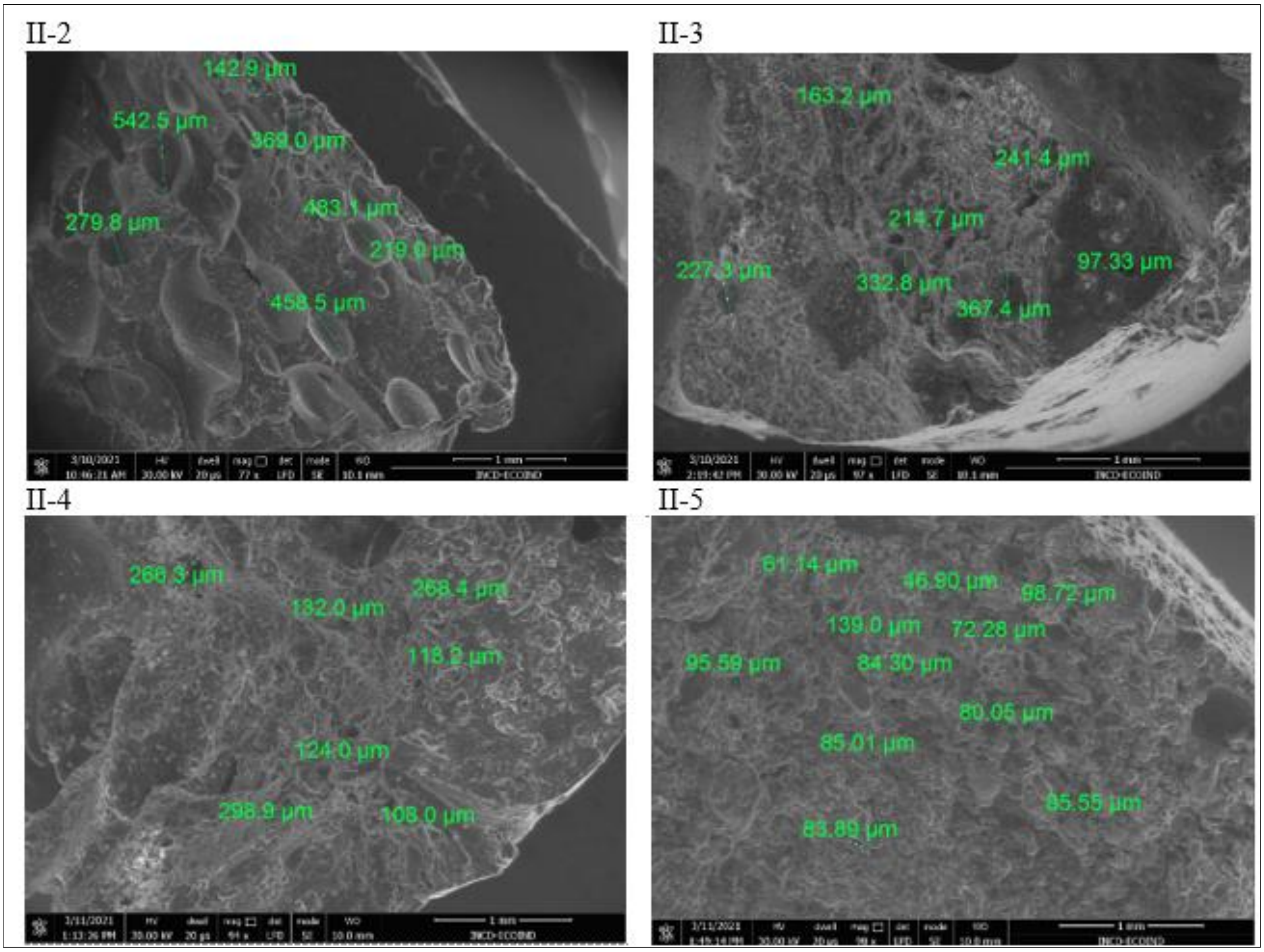
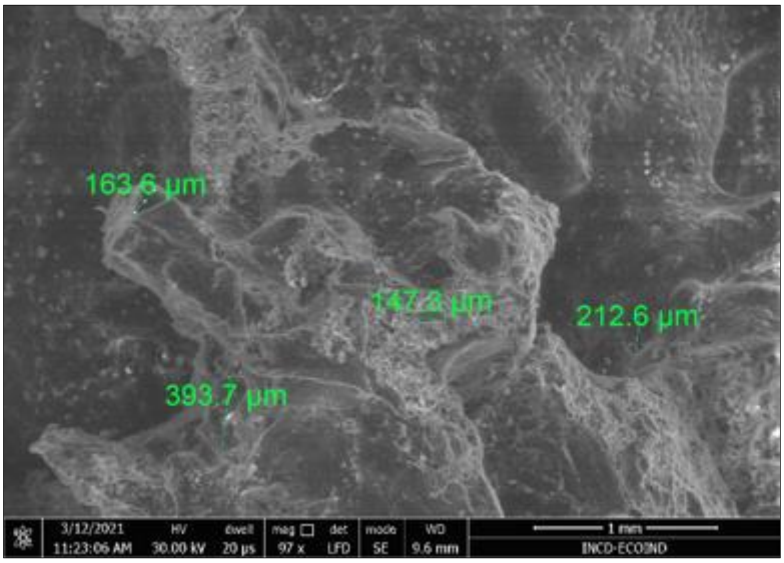


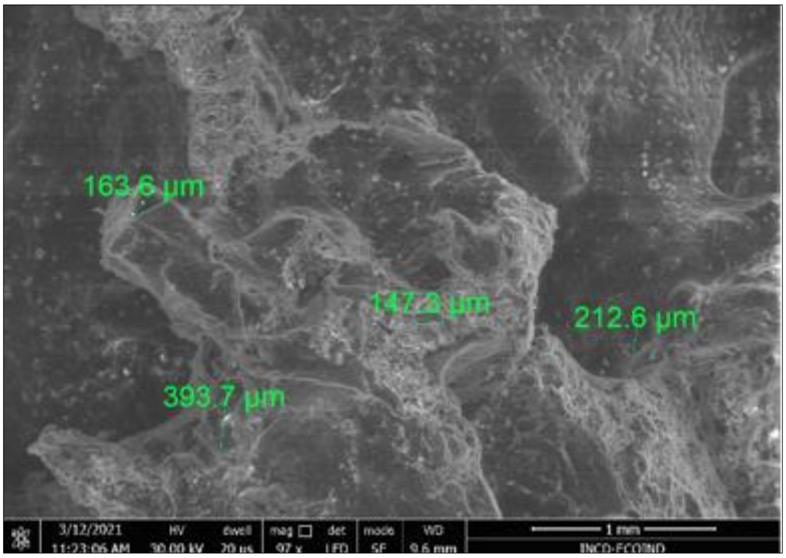
Figure 2. SEM micrographs for composites without additives

It should be noted that composites with additives present a smaller pore dimension as compared to that characterizing the composites without additives for the same percentage of feather flour. Additive addition into recipes led to a more compact composite and therefore, to the formation of pores with smaller size.

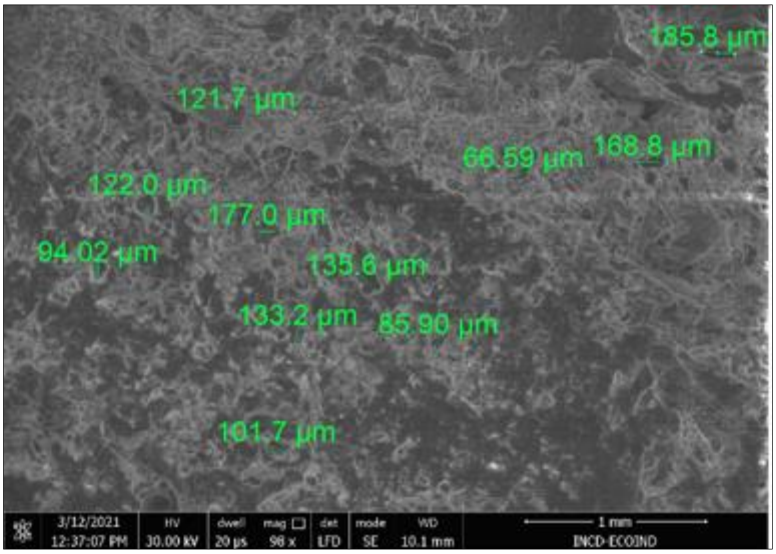
III-6



III-7



III-8



III-9

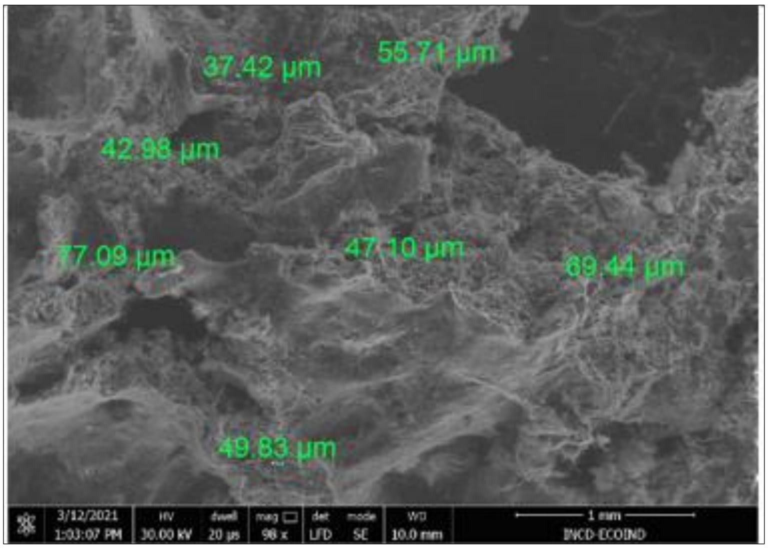


Figure 3. SEM micrographs for composites with additives

3.1.2. Characterization by thermal gravimetric analysis

Thermal gravimetric analyses were used to confirm the composition of tested samples. First, thermographs were obtained for the two main components of composites: recycled polypropylene (PPR) and feather flour (FF), which are presented within Figure 4.

If for PPR the thermograph presents only one main mass loss drop (between 230 - 430°C) which is characteristic to polypropylene decomposition, the thermograph for feather flow presents multiple mass losses drops characteristic to: water evaporation (up to 130°C), organic decomposition (230-590°C), decomposition of mineral compounds resulted from calcination (590-730°C), decomposition of mineral salts (730-900°C).

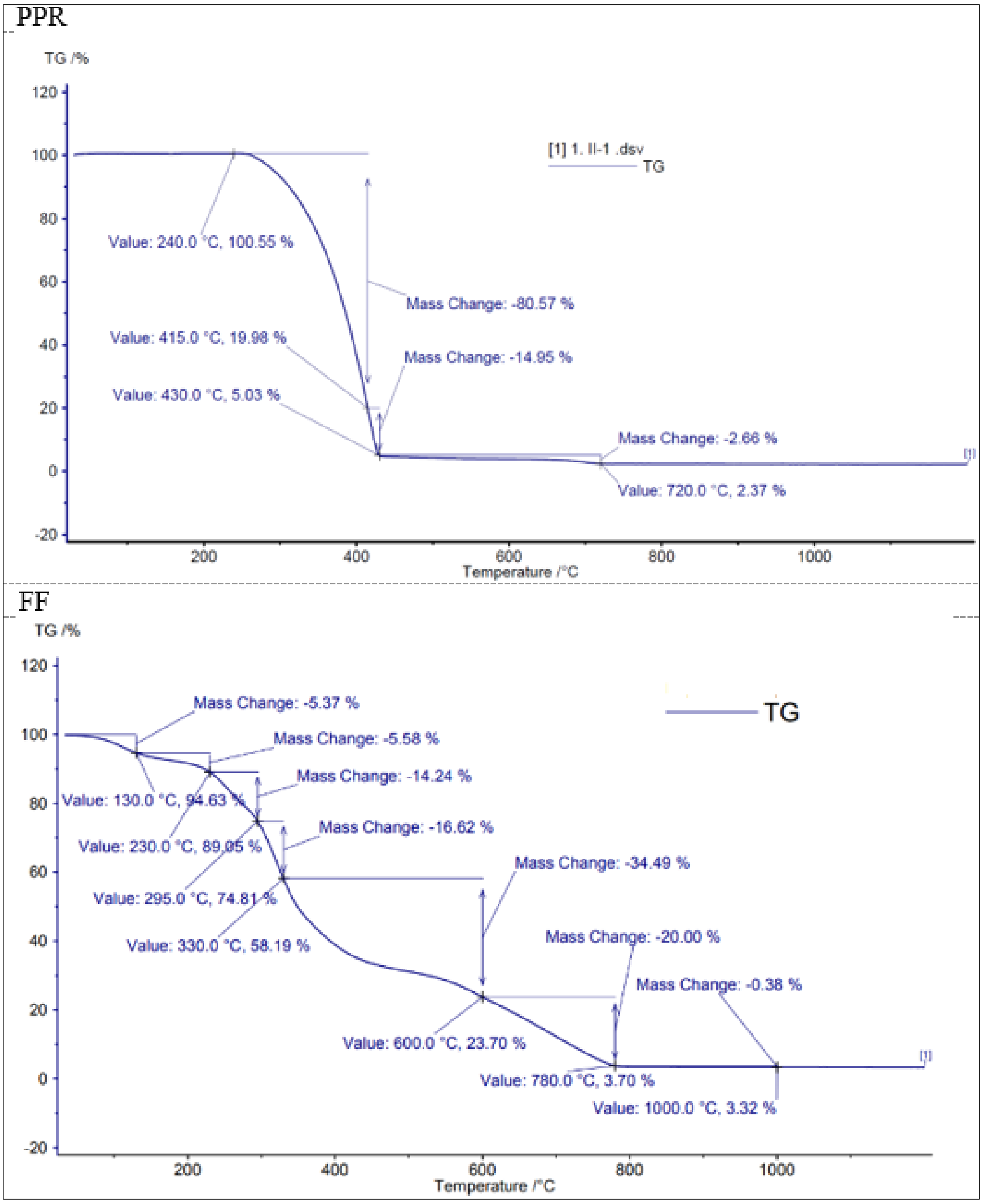
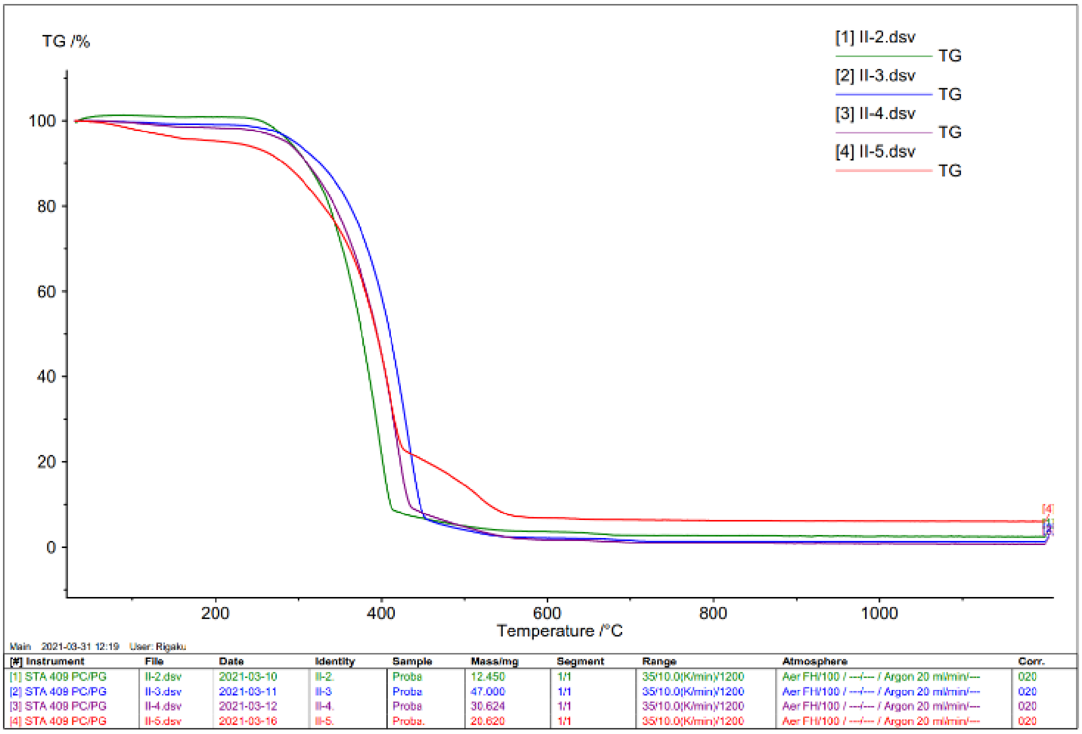


Figure 4. Thermographs for PPR and FF

Figure 5 presents thermographs for composites with or without additives.

Without additives



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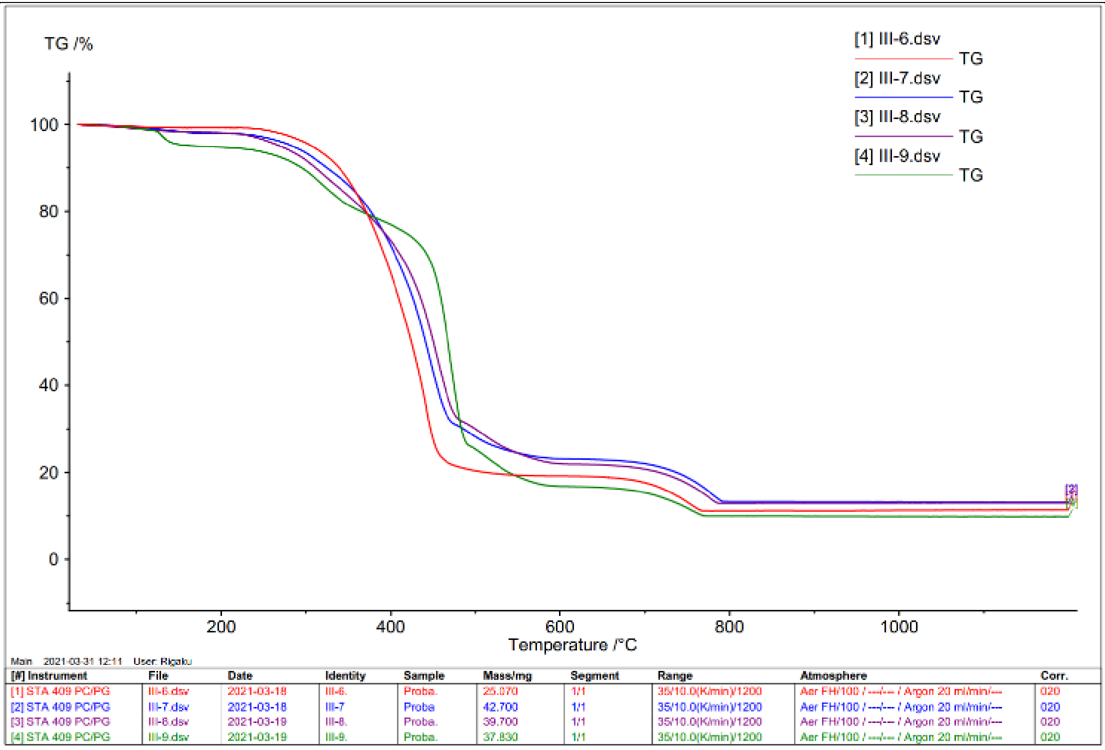
[#] Instrument	File	Date	Identity	Sample	Mass/mg	Segment	Range	Atmosphere	Corr.
[1] STA 409 PC/PG	II-2.dsv	2021-03-10	II-2.	Proba	12.450	1/1	35/10.0(K/min)/1200	Aer FH/100 / ---/--- / Argon 20 ml/min/---	020
[2] STA 409 PC/PG	II-3.dsv	2021-03-11	II-3	Proba	47.000	1/1	35/10.0(K/min)/1200	Aer FH/100 / ---/--- / Argon 20 ml/min/---	020
[3] STA 409 PC/PG	II-4.dsv	2021-03-12	II-4.	Proba	30.624	1/1	35/10.0(K/min)/1200	Aer FH/100 / ---/--- / Argon 20 ml/min/---	020
[4] STA 409 PC/PG	II-5.dsv	2021-03-16	II-5.	Proba.	20.620	1/1	35/10.0(K/min)/1200	Aer FH/100 / ---/--- / Argon 20 ml/min/---	020

With additives



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[#] Instrument	File	Date	Identity	Sample	Mass/mg	Segment	Range	Atmosphere	Corr.
[1] STA 409 PC/PG	III-6.dsv	2021-03-18	III-6.	Proba.	25.070	1/1	35/10.0(K/min)/1200	Aer FH/100 / ---/--- / Argon 20 ml/min/---	020
[2] STA 409 PC/PG	III-7.dsv	2021-03-18	III-7	Proba	42.700	1/1	35/10.0(K/min)/1200	Aer FH/100 / ---/--- / Argon 20 ml/min/---	020
[3] STA 409 PC/PG	III-8.dsv	2021-03-19	III-8.	Proba.	39.700	1/1	35/10.0(K/min)/1200	Aer FH/100 / ---/--- / Argon 20 ml/min/---	020
[4] STA 409 PC/PG	III-9.dsv	2021-03-19	III-9.	Proba.	37.830	1/1	35/10.0(K/min)/1200	Aer FH/100 / ---/--- / Argon 20 ml/min/---	020

Figure 5. Thermographs for tested composites

All thermographs presented in Figure 5 are including mass losses profiles for the two main components: PPR and FF and the obtained profiles are also in accordance with the PPR and FF percentages in a specific sample.

Therefore, it can be concluded that thermal gravimetric analysis confirmed that the composition of tested samples is in accordance with the composite's recipes.

3.2. Determination of sound absorption properties

The sound absorption coefficient is calculated as ratio between the sound energy absorbed by the environment through which wave is passing E_a and the incident wave energy E_i. The energy of the reflected wave is E_r. [11]

$$\alpha = \frac{E_a}{E_i} \tag{1}$$

$$\alpha = 1 - \left(\frac{E_r}{E_i}\right) \tag{2}$$

The reflection coefficient is calculated as the ratio between the reflected wave amplitude P_r and incident wave amplitude P_i [11].

$$r = \frac{P_r}{P_i} \tag{3}$$

The relationship between the sound absorption coefficient and reflection coefficient is:

$$\alpha = 1 - r^2 \tag{4}$$

In order to register the variation of sound absorption for bio composites materials without and with additives, those were separately analyzed and they are presented in Figure 6.

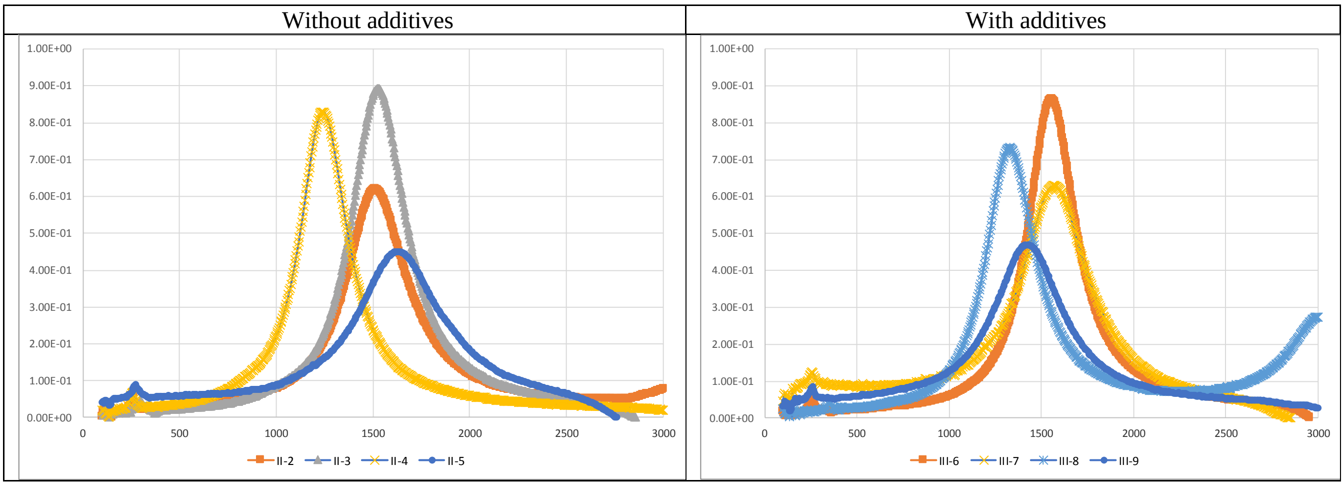

Figure 6. Sound absorption profiles for tested samples

According to graph profile of adsorption coefficient for II-2 sample, an increase of sound waves is observed within 200 - 1600 Hz domain. Maximum sound adsorption coefficient α_{max} = 0.62 was registered at 1512 Hz frequency. The relatively low value of adsorption coefficient is correlated with the average pore size of II-2 sample.

The highest value of α_{max} = 0.87 (at 1552 Hz) was registered for sample II-3. According to SEM micrographs, this composite presents a smaller average pore size as compared to sample II-2 due to the higher content of feather flour.

Sample II-4 registered α_{max} = 0.82 (at 1260 Hz) which is close to the highest value obtained for composites without additives. Even if the pore dimensions are smaller for II-4 as compared to II-3 samples, the decrease of α_{max} with the decrease of average pore size can be explained by the fact that in order to have good sound adsorption properties the pores within the material must be interconnected.

Same explanation seems to apply also for sample II-5 (which presents the smaller pore size) but registered α_{max} = 0.45 (at 1624 Hz), the lowest obtained value. Another possible explanation for this behavior can be the fact that sample II-5 is more compact as compared to the other composites without additives.

In the case of composites with additives the best α_{max} = 0.85 (at 1556 Hz) was registered for sample III-6 (10% feather flour) followed by III-8 (α_{max} = 0.73 at 1328 Hz), III-7 (α_{max} = 0.63 at 1568 Hz) and III-9 (α_{max} = 0.47 at 1420 Hz). It can be observed that both for composites with and without additives the poorest sound adsorption properties were exhibit by samples with the higher feather flow content and smaller pore dimensions, which made these composites more compact.

Summarizing, all tested samples present sound adsorption properties but the best results were obtained for a flour content of 20% (for the composites without additives) and 10% (for the composites with additives).

4. Conclusions

New biocomposites were prepared based on feather flour and recycled polypropylene, with and without additives. Biocomposites were characterized from morphological point of view via scanning electron microscopy. The SEM micrographs confirmed that average pore size is decreasing with the increase of feather flour content. Addition of additives proved to have a positive impact upon average pore size shrinking for the same feather flour content.

In order to confirm compositional characteristics of prepared composites thermal gravimetric analyses were performed and the obtained results proved that final biocomposites content is in accordance with their specific recipe.

All composites were tested in order to determine sound adsorption coefficient. All samples presented sound adsorption properties, but the best results were obtained for the composite without additives and with 20% feather flour content and the composite with additives with 10% flour content, which registered α max of 0.87 and 0.85 respectively.

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