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# BIOCOMPOSITES FOR SOUND ABSORPTION

**The use of natural materials to produce various types of products is becoming increasingly more popular, which also applies to composite products. The advantages of such products are not always high strength indicators, but above all their ecological character. In this respect, the best solution is to choose natural raw materials for both the reinforcement and the matrix of the composite. New possibilities of using biocomposites are increasingly being sought. A promising direction for the development of such composites is medical, construction, automotive, single-use products, or even recreational products. The paper presents the functional features of biocomposites made on the basis of various materials from renewable sources. Determining the sound absorption coefficient for thin, rigid composite plates, the possibilities of using wood flakes, sawdust, cork, paper, straw, feather calamus and flax fibers as reinforcement in sound-absorbing composites were evaluated and compared. The results of the research showed differences in the level of sound absorption, depending both on the type of reinforcement material and the frequency range of the sound.**

**Keywords:** **biocomposite, sound absorption, thermoplastic matrix, nonwoven**

## BIOKOMPOZYTY DO POCHŁANIANIA DŹWIĘKU

**Stosowanie materiałów pochodzenia naturalnego do wytwarzania różnego rodzaju wyrobów staje się coraz bardziej popularne, dotyczy to również wyrobów kompozytowych. Atutem takich wyrobów nie zawsze są wysokie wskaźniki wytrzymałościowe, ale przede wszystkim ich proekologiczny charakter. W tym aspekcie najlepszym rozwiązaniem jest wybór surowców naturalnych zarówno na wzmocnienie, jak i na osnowę kompozytu. Coraz częściej poszukuje się nowych możliwości zastosowania biokompozytów. Obiecującym kierunkiem rozwoju takich kompozytów jest branża medyczna, budowlana, motoryzacyjna, produktów jednorazowego użycia czy nawet produktów rekreacyjnych. W pracy wskazano cechy funkcjonalne biokompozytów wytworzonych na bazie różnych materiałów pochodzących ze źródeł odnawialnych. Wyznaczając współczynnik pochłaniania dźwięku przez cienkie, sztywne płytki kompozytowe, oceniono i porównano możliwości zastosowania wiórów drewnianych, trocin, korku, papieru, słomy, lotek pierza oraz włókien lnianych jako wzmocnienia/wypełnienia kompozytów dźwiękochłonnych. Wyniki badań pokazały zróżnicowanie stopnia pochłaniania dźwięku zarówno w zależności od rodzaju materiału wypełniającego, jak i zakresu częstotliwości dźwięku.**

**Słowa kluczowe:** **biokompozyt, pochłanianie dźwięku, termoplastyczna osnowa, włóknina**

## INTRODUCTION

One of the European Union's priorities is to maintain sustainable development, therefore the economy should help to minimize environmental and health hazards. It is important to introduce natural raw materials from renewable sources into the production of all products. A huge and perspective challenge for engineers is the design of new products based on such raw materials for ecological reasons. Products from natural raw materials, biopolymers and waste materials are increasingly being developed. In the case of composites, even the terms "biocomposite" and "green composite" have been created. As the literature source suggests, a biocomposite is: "… a material composed of two or more distinct constituent materials (one being naturally derived) which are combined to yield a new material with improved performance over individual constituent materials" [1]. Natural fibers, wood, cork, horsehair, nettle, leaves, and straw are usually used as filling material to produce biocomposites [2-6]. As the matrix material, among others, polylactide, starch, poly-hydroxybutyrate, are used. Such composites mean a smaller impact on the natural environment both at the production, use and post-use stages, easier recycling and smaller amounts of waste than in the case of composites based on chemical fibers [7]. In the literature the mechanical properties of such composites are usually given, and less often the properties defining their functionality [8]. Studies of the acoustic properties of composites based on biopolymer and natural fibers or straw indicate the high potential of such materials as absorbers of unwanted sounds [6, 9]. Sound absorption depends on the structure of the filling material, its fragmentation, surface development and the porosity of the composites. The simulation of absorption in a specific frequency range may be related to creating a proper composite structure (layered, solid), giving the appropriate structure of the composite surface, and its asymmetry [10]. There is no comparison in the literature in terms of the acoustic properties of composites reinforced with various natural materials. The paper presents biocomposites based on a biodegradable polymer obtained from renewable sources, i.e. maize meal, and seven different reinforcing materials of natural origin. Their comparison was based on acoustic and mechanical parameters.

## EXPERIMENTAL PROCEDURE

### Materials

For the composite reinforcement the following materials (Fig. 1) were used: (1) wood flakes, (2) fine sawdust, (3) ground cork, (4) paper cut in a shredder, (5) pieces of straw, (6) chicken feather calamus cut into small cubes, (7) flax fibers cut into several-centimeter sections. The materials were not modified to increase adhesion to the matrix. Each kind of reinforcing material was characterized by diversified length, width, structure, shape and fragmentation.

For the composite matrix material, Polylactide (PLA) fibres 6.7 dtex/64 mm, under the name of *Ingeo Fibre SLN2660D,* with a finishing composition containing polylactide resin and no hazardous compounds, supplied by the Far Eastern Textile Ltd. (Taiwan) were used. These fibres made of aliphatic polyester are completely biodegradable and pose no significant hazard to the environment. Their melting point is in the temperature range of 165÷170°C.

### Composite manufacturing

The thermoplastic composites were made with a multilayer structure consisting of two PLA nonwovens and one reinforcement alternating layer, in a pressing process. Each multilayer structure was composed of 10 nonwoven layers and 4 reinforcement layers. The appropriate mass of the reinforcing material (40 wt.%) was divided into portions, which were put uniformly onto two subsequent layers of nonwoven and the top of the multilayer structure was covered by two nonwoven layers. Flax fibres several centimeters long were arranged parallel in the same direction in each layer.

Needle punched nonwoven was manufactured from the PLA fibers. At the beginning fleece with a parallel system of fiber arrangement was obtained on the roller card. Then the needle punching process of the fleece layer was carried out on an Asselin needle punching machine (France). The following technological parameters were used: type of needles - 15 x 18 x 40 x $3^1/_2$ RB (Groz-Beckert®); number of needles punching - 40/cm$^2$; depth of needle punching - 12 mm. A needle punched nonwoven with a mass per square meter of 90 g/m$^2$ was obtained.


Fig. 1. Photographs of reinforcing materials

Rys. 1. Zdjęcia materiałów wzmacniających

 

The press conditions in the press machine with a water-cooling system (Hydromega, Poland) for all the multilayer structures were the same, i.e. temperature 170÷175°C, time 5 min, pressure 0.6 MPa. It was assumed that composite samples with similar thickness to allow assessment of the effect of the reinforcement type would be obtained.

## TESTING METHODS

The mass per square meter of nonwoven was established according to standard PN-EN 29073-1 (ISO 9073-1). The thickness of the composites was determined according to standard ISO 9073-2, while their density was estimated as the mass-to-volume ratio of the samples. The mechanical properties of the composites were studied in a unidirectional tensile test by means of a 3119-410 testing machine (Instron, UK) according to standard ISO 527-4. To characterize the acoustic properties of the composites the sound absorption coefficient was determined according to standard ISO 10534-2 within the frequency range of 500÷6400 Hz. A 4206 two-microphone small-sized impedance measurement tube (Kundt tube) (Brüel&Kjaer, Denmark) with two ¼-inch 4187 Condenser Microphones were used (Fig. 2). Three samples from each variant with a diameter of 29 mm were tested with the upper side to the sound.

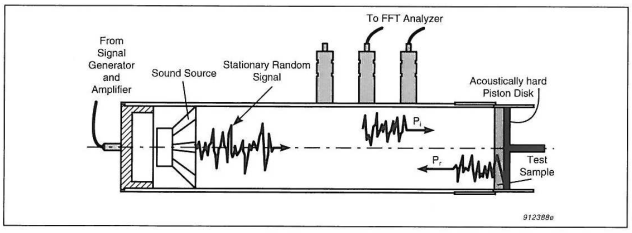


Fig. 2. Set-up with Kundt tube schematic diagram of impedance tube (technical documentation, Brüel&Kjaer, Denmark)

Rys. 2. Schemat rury impedancyjnej (dokumentacja techniczna, Brüel& Kjaer, Dania)

## RESULTS

From each type of reinforcing material, composites of a similar thickness were obtained. Their surfaces were smooth and slippery, without visible structural errors. The comparative characteristics of composites containing 40 wt.% reinforcement are presented in Table 1.

The thickness of the composites does not exceed 5 μm, and its diversity results from the variety of forms and structures of the used reinforcing materials. The apparent density of the composites ranges from 355 to 597 kg/m$^3$. In general, it can be noted that a greater thickness of the composite is associated with a lower density. The tensile strength is by far the highest in the case of the composite based on flax fibers, tested in the fiber direction, and is 15.5 MPa. The strength of the remaining composites is at the level of up to several MPa. These results confirm the results of earlier tests that the fiber is the form of reinforcement giving the composite the highest mechanical strength [11].

TABLE 1. **Physical and mechanical properties of composites**
TABELA 1. **Właściwości fizyczne i mechaniczne kompozytów**

| Composite | Thickness [mm] | Apparent density [kg/m$^3$] | Stress at maximum load [MPa] | Young's Modulus [MPa] | Elongation [%] |
|---|---|---|---|---|---|
| 1 - wood flakes | 4.93 | 355.4 | 1.3 | 88.6 | 1.6 |
| 2 - sawdust | 3.71 | 469.4 | 2.1 | 201.0 | 1.4 |
| 3 - cork | 4.29 | 392.2 | 0.7 | 112.1 | 1.0 |
| 4 - paper | 3.66 | 543.1 | 1.8 | 228.8 | 0.7 |
| 5 - straw | 4.98 | 309.7 | 4.3 | 546.1 | 1.2 |
| 6 - feather calamus | 2.85 | 597.3 | 2.7 | 440.7 | 1.1 |
| 7 - flax fibers | 2.62 | 536.4 | 15.5 | 1280.3 | 1.6 |

The differences in the structure of the reinforcing materials and consequently in the structure of composites are noticeable in the acoustic characteristics of the composites, presented in Figures 3-9.

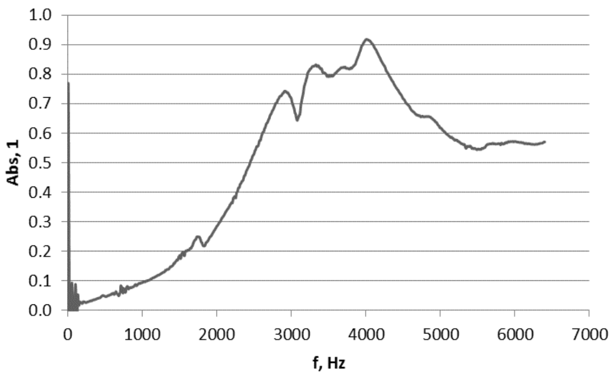


Fig. 3. Sound absorption coefficient of Composite 1 - wood flakes

Rys. 3. Współczynnik absorpcji dźwięku dla kompozytu 1 - wood flakes

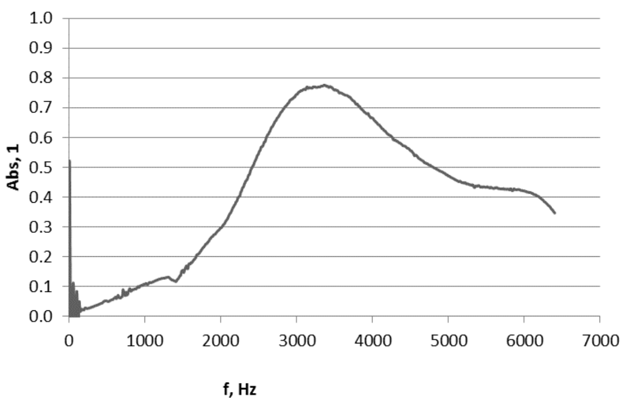


Fig. 4. Sound absorption coefficient of Composite 2 - wooden sawdust

Rys. 4. Współczynnik absorpcji dźwięku dla kompozytu 2 - wooden sawdust

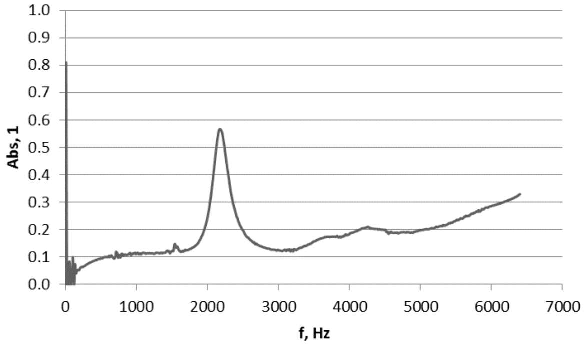


Fig. 5. Sound absorption coefficient of Composite 3 cork

Rys. 5. Współczynnik absorpcji dźwięku dla kompozytu 3 - cork

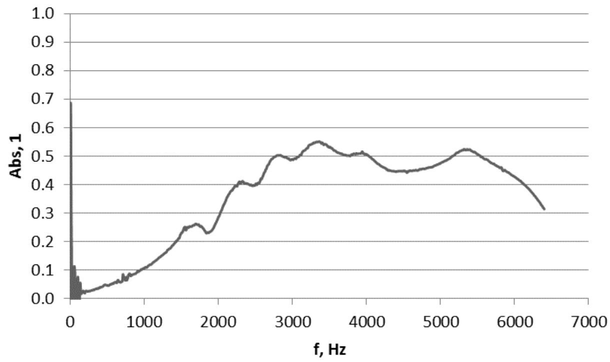


Fig. 6. Sound absorption coefficient of Composite 4 - paper

Rys. 6. Współczynnik absorpcji dźwięku dla kompozytu 4 - paper

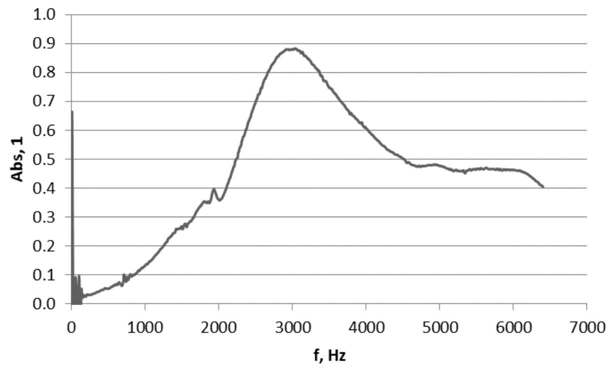


Fig. 7. Sound absorption coefficient of Composite 5 - straw

Rys 7. Współczynnik absorpcji dźwięku dla kompozytu 5 - straw

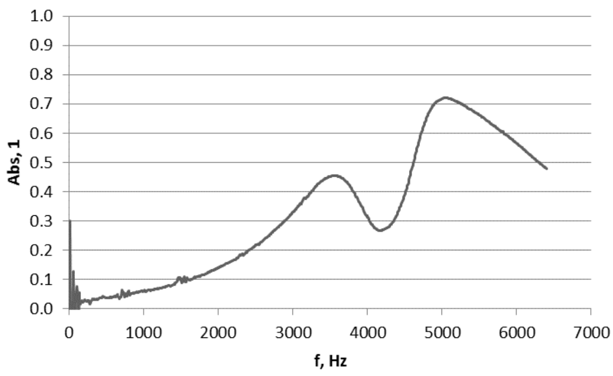


Fig. 8. Sound absorption coefficient of Composite 6 feather calamus

Rys. 8. Współczynnik absorpcji dźwięku dla kompozytu 6 - feather calamus

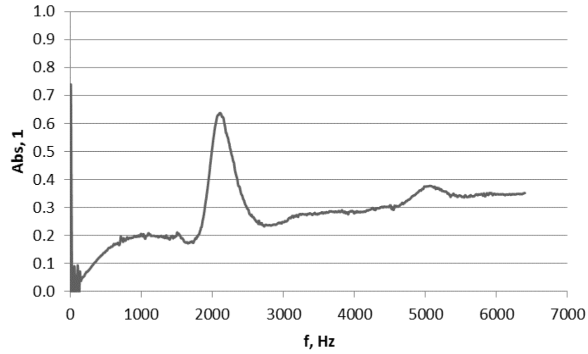


Fig. 9. Sound absorption coefficient of Composite 7 - flax fibers

Rys. 9. Współczynnik absorpcji dźwięku dla kompozytu 7 - flax fibers

Among the studied composites, in the largest sound frequency range the highest sound absorption is exhibited by Composite 1 - wood flakes (Fig. 3). In a similarly wide frequency range, sound is well absorbed by Composite 5 - straw (Fig. 7), and Composite 2 - sawdust (Fig. 4), with a clear maximum for the frequency of about 3000 Hz, and slightly worse absorbed by Composite 4 - paper (Fig. 6), but at a very even level in a wide range of frequencies. Composites 7 - flax fibers (Fig. 9), and 3 - cork (Fig. 5), have similar acoustic characteristics. A significant increase in the sound absorption coefficient is observed successively to values of approx. 0.63, 0.57 in the narrow frequency range of approximately 2100 Hz. In the remaining frequency range, the absorption of these composites is up to 0.4. Composite 6 - feather calamus (Fig. 8), exhibits different acoustic characteristics. Two maxima of sound absorption coefficient are observed. The first, a smaller increase to the value of 0.45 occurs for the frequency of approximately 3500 Hz and then a second, larger one to the value above 0.7 for the frequency of approx. 5000 Hz.

The acoustic tests, based on the determination of the sound absorption coefficient, showed that all the composites made on the basis of the selected natural materials can be called sound absorbing materials. Using the division into absorption classes presented in the PN-EN ISO 11654 standard and concerning the classification of sound absorbing products used in construction, the acoustic analysis of the obtained composites can be approximated. Table 2 shows the sound frequency ranges in which the composites exhibit an appropriate absorption coefficient.

Composite 1 - with wood flakes meets the criteria of Class A for a frequency of about 4000 Hz, because for such frequencies the sound absorption coefficient is slightly higher than 0.9. Class B criteria are met by Composite 1 - with wood flakes but in the narrow frequency range of 3250÷4300 Hz and Composite 5 - with straw also in the narrow range of 2600÷3330 Hz. Class C criteria are additionally met by Composite 2 - with sawdust, Composite 6 - with feather calamus and Composite 7 - with flax fibers. All the produced composites meet the criteria of Class D and, of course, Class E in a wide range of frequencies.

 

TABLE 2. **Acoustic classification of composites**
TABELA 2. **Klasyfikacja akustyczna kompozytów**

| Class, sound absorption coefficient | 1 - wood flakes | 2 - sawdust | 3 - cork | 4 - paper | 5 - straw | 6 - feather calamus | 7 - flax fibers |
|---|---|---|---|---|---|---|---|
| | sound frequency | | | | | | |
| A 0.9÷1 | 4000 | - | - | - | - | - | - |
| B 0.8÷0.85 | 3250÷4300 | - | - | - | 2600÷3330 | - | - |
| C 0.6÷0.75 | 2730÷5250 | 2500÷4250 | - | - | 2330÷4000 | 4730÷5800 | 2000÷2130 |
| D 0.3÷0.55 | 2000÷6400 | 2000÷6400 | 2000÷2400<br>6200÷6400 | 2000÷6400 | 1600÷6400 | 3800÷6400 | 1860÷2530<br>4500÷6400 |
| E 0.15÷0.25 | 1250÷6400 | 1500÷6400 | 1750÷6400 | 1100÷6400 | 1000÷6400 | 1800÷6400 | 460÷6400 |

## CONCLUSIONS

The work showed that it is possible to successfully use materials of natural origin as reinforcement in sound-absorbing biocomposites. Using different materials as the reinforcement, in the same weight percentage, a comparison of the physical, mechanical and acoustic properties of the composites was made. Both the thickness and apparent density of the composites were even 90% different. The tensile strength of the composite based on flax fibers is much higher than that of those reinforced by particles and is about 20 times greater than the lowest strength, i.e. for the cork-based composite and about 3.6 times greater than the highest strength, i.e. for the straw-based composite. The conducted comparative tests made it possible to assess the suitability of natural materials as a component of a composite that absorbs sound of given frequencies. The composites exhibit different values of the sound absorption coefficient not only depending on the type of filling/ reinforcing material, but also on the sound frequency range. As a reinforcing material of a composite absorbing sound in a wide frequency range from 2,000 to 6,400 Hz, with a minimum sound absorption coefficient of 0.3, the wood flakes, fine sawdust, paper cut in a shredder, and pieces of straw can be used. The best sound absorption effect, i.e. the highest values of the absorption coefficient and in the largest frequency range, was obtained using wood flakes as the reinforcement in the composite. Using the above studies illustrating the nature of the absorption coefficient - the sound frequency dependence for a given type of composite - we can develop optimal conditions to produce such composites, i.e. the contribution of reinforcing material, modification of its surface, technological parameters of the pressing process, which would allow one to obtain a composite structure providing maximum sound absorption in given frequency range. It can be assumed that in order to obtain higher absorption and in a wider range of frequencies, a perspective solution will be to use more than one reinforcing material in the composite simultaneously.

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