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Development of glutinous biocomposite materials filled with coffee grounds

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Abstract. The intensive development of biocomposite materials is associated with the use of waste from agricultural production or the food industry as raw materials. Such raw materials are renewability and eco-friendly, but require special processing for preparation for use as a filler and development of methods of forming biocomposite products, which determines the high relevance of research in this direction. The aim of the work was to study the intensity of the influence of the mechanical and thermal fields on the mechanical properties and nature of the structuring of glutinous biocomposite materials with a high content of coffee grounds (190-200 wt. parts). The forming technology of biocomposite materials consisted in heat treatment of the composition. Next stages are pressing and holding of composition at a temperature of 150°C under a pressure of 8-11 MPa. The work used the methods of determining a compressive strength and an impact toughness. The method of infrared spectroscopy was also used to study structuring processes. It was established that the use of coffee grounds in the quantity of 200 wt. parts provides an increase in compressive strength up to 75.8 MPa under the condition of forming a biocomposite material with a density of 1.17 g/cm3. An increase in the resistance of biocomposites to dynamic loads occurs in the case of the introduction of a filler in the amount of 190 wt. parts using a preliminary

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pressing at a specific load of 8 MPa. The practical significance of this work lies in developing an optimal thermo-mechanical processing mode, involving maximum exposure of the composition in a press mould within a thermal field for 2 hours, which enhances the mechanical properties of glutinous biocomposite materials

Keywords: glutinous matrix; thermo-mechanical treatment; compressive strength; impact toughness; IR spectrogram; structuring

Introduction

The ever-increasing demand for biodegradable and cost-effective materials is driving many research efforts towards the development of biocomposites based on natural components. The authors R. Scaffaro *et al.* (2022) in their works optimised the composition taking into account new requirements and recommendations of the circular economy and zero waste. The scientists R. Scaffaro *et al.* (2021) identified the advantages of natural fillers, which are undoubted from the economic and environmental points of view, but their introduction into bioplastics often causes deterioration of mechanical properties, especially under the influence of high loads. An important challenge in the field of polymer composite materials is the development of biocomposite compositions and forming technologies through the incorporation of natural fillers into bioplastics, which are produced in relatively large quantities. The researchers S.M. Shahabaz *et al.* (2021) identified positive effects as a result of obtaining environmentally friendly materials based on renewable raw materials, which will be able to combine high economic efficiency with satisfactory mechanical strength.

For the development of biocomposite materials, the authors T. Shevchenko *et al.* (2022) widely used biopolymers such as polylactic acid (PLA), cellulose esters, polyhydroxyalkanoates (PHA) and starch-based plastics. T.D. Moshood *et al.* (2022) defined the advantages of biological resins over synthetic polymers because they are energy-efficient in production (65% less energy required for production), safe (non-toxic at all stages of the life cycle and especially at the disposal stage, as biological decomposition into eco-friendly components occurs), suitable for recyclable, renewable (made from biomass) and environmentally friendly (68% less greenhouse gas emissions).

Mainly, the properties of natural fibre-reinforced biocomposites depend on the chemical composition of the fibre and the polymer matrix. The type and orientation of natural fibres or microfibrils, fibre modification, modifier type, fibre-to-polymer mass ratio, the type of moulding or processing technology, physical properties, and the quality of the interfacial connection between the reinforcing materials and the matrix are the parameters that determine the mechanical properties of biocomposites. The researchers M. Akter *et al.* (2022) found that high adhesive strength ensures full load transfer between the fibre and the polymer matrix.

Natural fibres have a porous structure that provides high heat and noise insulation. This is a class of materials that can be easily processed, so they are suitable for a wide range of applications, such as the manufacture of packaging and consumer goods, in the construction industry (roofing, flooring, windows, doors, furniture), in the automotive and aerospace industries, in the military, electronics and medical industry (prostheses, bone plates, orthodontic arches). M. Melnychuk *et al.* (2023) improved the adhesion between the filler and the polymer using a special chemical treatment of the components with the addition of talc as an intermediate agent to improve compatibility. A significant disadvantage of natural fibres is the presence in the chemical composition of hydroxyl groups (OH), which are able to attract water molecules, as a result of which the fibres become saturated with moisture. The authors M.R. Mansor *et al.* (2020) described the effect of such a defect on the formation of the structure, which leads to the formation of cavities at the interface of the biocomposite components, which effects on their mechanical properties and loss of dimensional stability.

The positive effect of the use of secondary raw materials of the agricultural sector and food industry waste, in particular straw or husks, was determined in the work of M. Jerman *et al.* (2021). This ensures the expansion of the spectrum of possible areas of application of biocomposite materials and at the same time allows to reduce the negative impact on the environment.

The authors J. Dušek *et al.* (2021) introduced a highly energy-efficient and eco-friendly composite building material utilising rapeseed straw and a sustainable binder. The binder comprises bone glue combined with sodium lignosulfonate. In order to enhance the properties of the material, the rapeseed straw particles undergo a surface modification process involving treatment with water and sodium hydroxide. This treatment increases the bulk and matrix density, thereby improving the adhesion strength between the chopped rapeseed straw particles and the bone glue, as compared to the reference material. Significant moisture saturation of all developed biocomposites in conditions of relative humidity above 75% limits their practical application. Therefore, the use of the developed biocomposite materials is possible in contact with a dry environment, for example, for the manufacture of packaging of solid or loose products, cladding and insulation of interior walls. The scientists V.P. Kashytskyi *et al.* (2023) developed biocomposite materials containing sodium sulfate, which is used as a modifying additive to intensify the structuring process of biocomposites. The work established the effect of the modifying additive on the compressive strength of biocomposites and features of structuring at different temperatures.

The purpose of the study was to determine the influence the density, the optimal content of fine filler and the mode of thermo-mechanical treatment of the composition on the mechanical characteristics of glutinous biocomposite materials filled with coffee grounds.

Materials and Methods

Samples of biocomposite materials for research were formed on the basis of a biopolymer matrix (glutin) and filler from food waste (coffee grounds). The biopolymer binder was prepared by dissolving granules of bone glue (glutin) in water. The physicochemical properties of bone glue granules correspond to the technical data of 63000 Bone Glue, Pearls (2016). The coffee grounds were previously dried and sieved. The preparation of the biocomposite material composition was carried out by mechanically mixing the components in a specified ratio. Mixing was carried out using a laboratory mill with a high frequency of rotation (20 kHz) of a petal-type working body. Before the formation of biocomposite samples, moisture was removed from the composition up to 20% by holding the mixture in a thermal field at a temperature of 50-60°C for 20-30 minutes. Biocomposite samples were formed in a mould by pressing the composition with subsequent exposure in a thermal field. The main mode of heat treatment of the composition consists of two stages, that ensures the process of forming the biocomposite material. After the first stage of exposure of biocomposite samples with a duration of 1 hour at a temperature of 150°C, additional pressing is carried out in order to eliminate voids and cavities, which are formed as a result of removing moisture at high temperature. The dense structure of the composites is achieved through the formation of physical and chemical bonds between the components while the binder remains in a liquid state. The material is then subjected to thermal treatment for 1 hour at a temperature of 150°C. Following the second stage of thermal exposure, the mould is removed from the drying chamber and allowed to cool gradually to room temperature to prevent the development of internal stresses. Once cooled, the biocomposite samples are extracted from the mould and tested.

Compressive strength was determined according to the ASTM D695-23 (2023) method on cylindrical samples with a height of 30 mm and a diameter of 20 mm. Impact toughness was determined on samples 60 mm long with a square section (10×10 mm) according to the ASTM D256-23e1 (2023). The structuring of biocomposites was investigated using an IR spectrometer IRAffinity-1S (Shimadzu, Japan) in the frequency range 400-4000 cm^{-1}. The single-beam method in reflected light was used. Wave numbers were determined using the LabSolution IR computer program.

Results and Discussion

Food industry waste in the form of a finely dispersed powder, which is obtained as a result of processing coffee grounds, can be used as fillers for glutinous biocomposite materials. The exploration of optimal finely dispersed filler content in the biopolymer matrix, along with the assessment of density and thermo-mechanical processing modes, facilitated an in-depth analysis of the impact of mechanical and thermal fields on the properties of biocomposite materials enriched with coffee grounds.

Biocomposite materials containing 190 wt. parts coffee grounds per 100 wt. parts of biopolymer binder with density of 1.17 g/cm^3 have a compressive strength of 68.5 MPa (Fig. 1). The limit of compressive strength (65.3 MPa) of the biocomposite with a higher density of 1.38 g/cm^3 is slightly reduced by 4-5% in comparison with the strength of biocomposites with a density of 1.17 g/cm^3. This occurs due to the development of internal stresses in the system, resulting from the limited mobility of macromolecular segments within the glutin matrix after moisture removal and the binder's transition to a solid state. The compressive strength of the biocomposite material with a density of 1.59 g/cm^3 further decreases by 11-12% in comparison with the mechanical strength of biocomposites with a density of 1.17 g/cm^3. The biocomposite material is in a compressed state, which makes it difficult to move segments of macromolecules of the glutin matrix and reduces resistance to static load. The highest value of compressive strength (75.8 MPa) was obtained for biocomposite materials with the content of 200 wt. parts coffee grounds and a lowest density of 1.17 g/cm^3. The mechanical properties of these biocomposites improve by 9-10% compared to those with a filler content of 190 wt. parts, assuming a similar material density of 1.17 g/cm^3. The enhancement in compressive strength is attributed to the partial substitution of the biopolymer matrix with filler particles. This indicates the ability of the filler to establish robust adhesive bonds with the glutinous matrix and its greater resistance to compression compared to the biopolymer matrix. The mechanical characteristics of such biocomposites are also determined by the size of areas which have high cohesive strength of the polymer matrix and fillers. The compressive strength of the composites decreases to 65.3 MPa as the density of the composites increases to 1.38 g/cm^3. The compressive strength of biocomposites is 60.5 MPa in the case of their density of 1.59 g/cm^3. It was found that the compressive strength decreases by 13-15% for biocomposites with a density of 1.38 g/cm^3 and by 20-22% for biocomposites with a density of

1.59 g/cm^3 in comparison to the compressive strength of biocomposites with a density of 1.17 g/cm^3. A significant decrease in this characteristic occurs due to an increase in the density of biocomposites up to 1.59 g/cm^3, as a stress state of materials is formed. The compressive strength for biocomposites with a filler content of 200 wt. parts is higher by 12-13% for biocomposites with a density of 1.38 g/cm^3 and by 7-8% for biocomposites with a density of 1.59 g/cm^3 compared to the strength of biocomposites containing filler of 190 wt. parts. This is attributed to the reduced content of the biopolymer matrix in the case of testing biocomposites with a filler content of 200 wt. parts due to the low ability of the glutinous polymer to relax residual stresses, as a stable glutinous structure with high stiffness of amino acid macromolecule chains is formed. It is necessary to increase the mobility of segments of macromolecules of the glutin matrix in the case of the formation of biocomposite materials with a high density. A similar issue is considered in the works of authors P.P. Parlevliet *et al.* (2007) and S. Chava *et al.* (2022), who investigated the effect of residual stresses on the mechanical properties and durability of polymer composites based on thermoplastic polymers. Several mechanisms for removing thermal residual stresses, which are based on the modification of the components of composite materials and the development of the heat treatment mode, are considered. The effect of the duration of the thermal field on the compressive strength was investigated in order to optimise the technological process of forming biocomposite materials with a density of 1.17 g/cm^3, as a result of which thermo-mechanical processing regimes with different durations at the first and second stages were developed (Table 1).

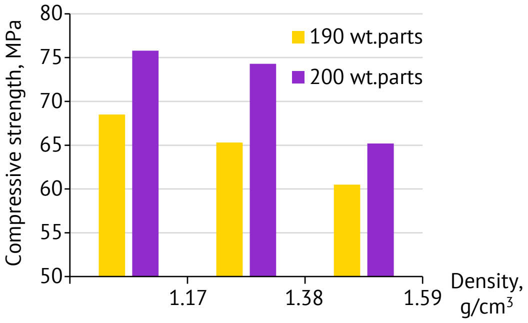

Figure 1. *Compressive strength of biocomposite materials depending on the content of coffee grounds in the biopolymer matrix and the density of biocomposites*
Source: *developed by the authors*

Table 1. *Modes of thermo-mechanical treatment of biocomposite samples*

Content of coffee grounds, wt. parts	**Modes of thermo-mechanical treatment**			
	1	2	3	4
190	1 hour 150°C + pressing + 1 hour 150°C	1 hour 150°C + pressing + 30 min. 150°C	30 min. 150°C + pressing + 1 hour 150 °C	30 min. 150°C + pressing + 30 min. 150°C
200				

Source: *developed by the authors*

Among biocomposite materials with a density of 1.17 g/cm^3 and a filler content of 190 wt. parts the highest compressive strength (73.2 MPa) has the materials formed according to the main mode of thermo-mechanical treatment (1 hour at 150°C + pressing + 1 hour at 150°C, mode No. 1 of Table 1) (Fig. 2). The characteristics of biocomposites decrease by 19-20% in the case of shortening the exposure time at the second stage of thermo-mechanical treatment to 30 min. (1 hour 150°C + pressing + 30 min. 150 °C, mode No. 2 of Table 1) compared to the strength of biocomposites, which are formed according to the main processing mode. This is due to insufficient thermal influence on the processes of formation of new physicochemical bonds between active groups of macromolecules as a result of compaction of components after applying the compression operation.

Reducing the exposure time at the first stage of thermo-mechanical processing to 30 minutes followed by an exposure of 1 hour at the second stage (30 min. at 150°C + pressing + 1 hour at 150°C, mode No. 3 of Table 1) leads to a decrease of 28-30% compressive strength (52.5 MPa) compared to the strength of biocomposites formed by the main processing mode. This suggests that thermal energy plays a more dominant role in the structuring processes of biocomposite materials compared to the heating of the composition in the second stage. This stage involves the transition of the glutinous binder into a liquid state, its redistribution within the biocomposite, and the wetting of the coffee grounds particle surfaces, followed by the penetration of the binder into the porous structure of the organic filler. In the work of the authors V. Kashytskyi *et al.* (2023) attribute a high compressive strength of biocomposite materials to the uniform distribution of the biopolymer binder between the filler particles, which occurs during the melting of the glutin solution under the influence of a temperature of 150°C. Biocomposites have higher values of compressive strength in the case of exposure in a thermal field for 2 hours compared to exposure for 4 hours. Shortening the exposure time in two stages of thermo-mechanical treatment to 30 minutes (30 min. 150 °C + pressing + 30 min. 150 °C, mode No. 4 of Table 1) leads to the formation of a biocomposite material with the lowest of compressive strength (47.7 MPa). This is due to the fact that the composition receives an inadequate amount of thermal energy, which is essential for the redistribution of the glutinous binder and the formation of physicochemical bonds between the components of the biocomposite material. The authors T. Gurunathan *et al.* (2015) focused attention on various methods of surface modification, which made it possible to improve the adhesion of the fibre to the matrix and accordingly the mechanical properties of biocomposites.

Experimental results showed that the highest compressive strength 79.6 MPa has biocomposites containing 200 wt. parts of filler and with a density of 1.17 g/cm^3. These biocomposite materials were formed according to the main mode of thermo-mechanical processing (1 hour at 150°C + pressing + 1 hour at 150°C, mode No. 1, Table 1). Compressive strength of biocomposites with a coffee grounds content of 200 wt. parts decreases by 24-25% in the case of a reduction in the duration of exposure at the second stage of heat treatment (1 hour 150°C + pressing + 30 min. 150°C, mode No. 2 of Table 1) compared to an exposure time of 1 hour during thermo-mechanical treatment according to main mode. The reduction in characteristics is attributed to the insufficient duration of exposure in the thermal field, which is essential for the formation of the biocomposite material's structure following the additional compression of the composition. This leads to an uneven distribution of the glutinous binder in the composition with a higher content of filler particles compared to the degree of filling of 190 wt. parts. In this case, the compressive strength limit of biocomposites with a content of 200 wt. parts differs by only 2% compared to the strength of biocomposites containing 190 wt. parts of filler. A similar difference in the strength values of biocomposites with different filler content (190 wt. parts and 200 wt. parts), which are formed according to the main processing mode, is 8-9%. This indicates the dominant effect of thermal energy in the first stage of processing compared to an increase of 10 wt. parts of the amount of filler in the system.

A decrease in compressive strength by 30% and 36% occurs in the case of a decrease in the duration of exposure at the first stage of thermo-mechanical treatment (30 min. 150°C + pressing + 1 hour 150°C, mode No. 3, Table 1) and at two stages processing (30 min. 150°C + pressing + 30 min. 150°C, mode No. 4, Table 1) respectively (Fig. 2). These results correlate well with the compressive strength values of biocomposite materials with a filler content of 190 wt. parts, which is explained by the insufficient amount of thermal energy for the formation of glutinous biocomposites. Resistance to dynamic loads was determined on biocomposite samples with a filler content of 190 wt. parts and 200 wt. parts. The samples were obtained using the method of pressing at the initial stage of forming the composition followed by thermo-mechanical processing according to the basic mode (1 hour at 150°C + pressing + 1 hour at 150°C). The highest value of impact toughness (3.55 kJ/m^2) has biocomposite materials (Fig. 3) with a filler content of 190 wt. parts and a pressure formation of 8 MPa. Formation of biocomposite materials under the pressure of 11 MPa leads to a 9-10% decrease in impact toughness compared to samples with a pressure formation of 8 MPa. This is due to the deformation of the filler particles, which have low mechanical characteristics, as a result of which their rapid destruction occurs during the movement of the crack. The work of the authors R. Gunti *et al.* (2018) presented that resistance to dynamic loads increases as strength and filler content increase. The use of processed sisal and jute fibres provides an increase in impact toughness by 111.5% and 22.3%, respectively. However, the technological process of forming biocomposite products becomes more complex in this case.

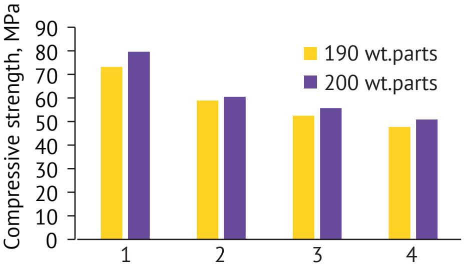

Figure 2. *Compressive strength of biocomposite materials depending on the mode of thermo-mechanical treatment (Table 1)*

Note: *1 – 1 hour 150°C + pressing + 1 hour 150°C; 2 – 1 hour 150°C + pressing + 30 min. 150°C; 3 – 30 min. 150°C + pressing + 1 hour 150°C; 4 – 30 min. 150°C + pressing + 30 min. 150°C*

Source: *developed by the authors*

Impact toughness of biocomposite materials with a filler content of 200 wt. parts and a pressure formation of 8.0 MPa is 3.33 kJ/m^2. The impact toughness of biocomposites (3.06 kJ/m^2) increase in 6.5% with an increase in the specific compression load of the composition to 11.0 MPa compared to the impact toughness of biocomposites formed under a specific load of 8 MPa. The formation of biocomposite materials using a higher pressure of formation (11 MPa) provides a higher density of the material, but at the same time, the degree of deformation of the particles, which have less resistance to the influence of dynamic loads, increases.

The lower values of the impact viscosity of biocomposite materials with a higher content of filler (200 wt. parts) are explained by the presence of a larger number of deformed particles of coffee grounds, that are not able to resist the crack movement (Fig. 3).

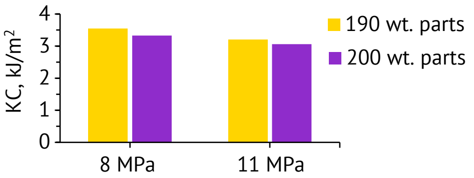

Figure 3. *Impact toughness of biocomposite materials depending on the pressing pressure during the formation of samples*
Source: *developed by the authors*

The crack propagation direction of biocomposite samples, which were formed under the action of a specific load of 8 MPa, has a deviation of 9-11° (Fig. 4, a) from the direction of the dynamic load action vector. In the case of destruction of biocomposite samples, which were formed under the action of a specific load of 11 MPa, the deviation is 1-2° (Fig. 4, b) from the direction of the dynamic load action vector. This indicates the biocomposite material's low resistance to dynamic loads, which was formed under a specific load of 11 MPa, as the crack propagates with minimal energy required to overcome the obstacles created by the deformed coffee grounds particles. A complex set of absorption bands at frequencies of 1400-1800 cm^{-1} was recorded on the IR spectrograms (Fig. 5) for the biocomposite materials with coffee grounds formed under pressure of 8 MPa and 11 MPa. There are characteristic absorption bands on the IR spectrogram (Fig. 5, a) for the biocomposite material formed under a pressing pressure of 8 MPa at frequencies of 1458.25 cm^{-1} with optical density D = 0.625 and peak area S = 23.22%, 1523.83 cm^{-1} with optical density D = 0.618 and peak area S = 17.46%, 1543.12 cm^{-1} with optical density D = 0.627 and peak area S = 11.69%. These absorption bands at the specified frequencies correspond to asymmetric deformation $-CH_3$ and deformation $-N-H$ vibrations. Absorption bands at frequencies of 1639.56 cm^{-1} (D = 0.662, S = 9.01%) and 1655.00 cm^{-1} (D = 0.669, S = 18.02%) indicate the presence of valence $-C=O-$ and $-C=C-$ oscillations. Absorption bands at frequencies of 2345.54 cm^{-1} (D = 0.580, S = 25.37%) and 2372.55 cm^{-1} (D = 0.584, S = 31.17%) inform about the presence of valence vibrations in the biocomposite material $-P-H$ groups. There are on the IR-spectrogram a transmission band at a frequency of 2924.21 cm^{-1} (optical density D = 0.719 and peak area S = 87.89%), which corresponds to asymmetric valence vibrations of CH_3 groups. The identified characteristic absorption bands corresponding to certain functional groups indicate a sufficient degree of structuring of the biocomposite material formed under a pressing pressure of 8.0 MPa. The authors J.-M. Raquez *et al.* (2010) determined the effectiveness of using biopolymer matrices with a high modulus of elasticity, strength, durability and resistance to thermal stress and chemical effects, which is ensured by high cross-linking density as a result of the formation of additional connections between the components.

Figure 4. *The general appearance of biocomposite samples with a filler content of 190 wt. parts after the impact toughness test*
Note: *biocomposites are formed under pressure: a – 8 MPa; b – 11 MPa*
Source: *developed by the authors*

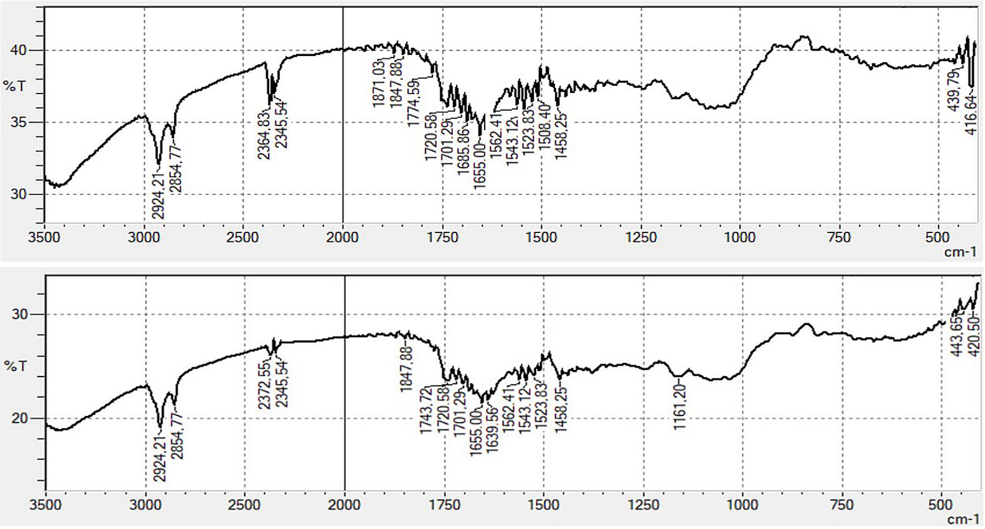

Figure 5. *IR spectrograms of biocomposites formed under a pressing pressure*
Note: *a – 8 MPa; b – 11 MPa*
Source: *developed by the authors*

Characteristic absorption bands at similar frequencies were recorded for the biocomposite material formed under a pressure of 11 MPa (Fig. 5, b): 1458.25 cm^{-1} (D = 0.442, S = 9.74%), 1523.83 cm^{-1} (D = 0.438, S = 12.13%), 1543.12 cm^{-1} (D = 0.447, S = 12.16%), 1655.00 cm^{-1} (D = 0.468, S = 15.08%). These absorption bands are characterised by significantly lower values of optical densities and smaller peak areas, which indicates a lower degree of structuring of biocomposite materials at a higher forming pressure (11 MPa). The absorption band at the frequency of 2364.83 cm^{-1} (D = 0.441, S = 21.10%) is shifted to the region of lower wave numbers, indicating the enhanced structuring of the biocomposite formed under higher pressing pressure. The recorded absorption band at higher frequencies of 2924.21 cm^{-1} is also characterised by lower values of optical density (D = 0.494) and peak area (S = 73.82%).

Therefore, the developed biocomposite materials, formed under different pressures of 8 MPa and 11 MPa, have a high degree of structuring. This is indicated by the complex spectrum of absorption bands present on the IR spectrogram, which correspond to the existence of functional groups. Biocomposites formed under a lower pressing pressure of 8 MPa have lower values of optical densities and larger peak areas of characteristic absorption bands compared to biocomposite materials formed under a higher pressing pressure (11 MPa). This indicates a higher degree of structuring of biocomposites formed at a lower pressing pressure of 8 MPa due to the formation of a greater number of bonds in the materials. This can be explained by the fact that under higher pressure the fibres are additionally deformed and destroyed. The elastic aftereffect is more pronounced at a higher pressure, which leads to the destruction of already formed bonds in the material. These results explain the obtained lower values of impact toughness for biocomposites formed under higher pressing pressure (11 MPa).

As a result of analysing other authors' sources, it was found that the authors R. Bodîrlău *et al.* (2014) found a decrease in the flexibility of starch polymer chains in composites due to the use of modified cellulose microparticles in a plasticised starch matrix. Authors M. Morreale *et al.* (2015) explain that the modulus of elasticity increases without decreasing the tensile strength of biocomposite materials containing wood flour due the high adhesion between the filler particles and the biopolymer matrix, which was confirmed by SEM analysis. The scientists R. Scaffaro *et al.* (2021; 2022) indicated that the improvement of the mechanical characteristics of biocomposite materials with a hybrid content of lamellar and fibrous fillers or fillers from marine and agricultural waste is associated with the formation of strong interfacial regions, which have high adhesive strength between the components.

In the work of the researchers J. Dušek *et al.* (2021) the density of the biocomposite material increased as a result of surface treatment of rapeseed straw with water or sodium hydroxide. This treatment preserves the integrity of the filler and enhances the adhesion between rapeseed straw and bone glue, resulting in improved mechanical properties of the biocomposites. A negative consequence of this treatment is the intensive absorption of moisture by the filler, which requires an additional thermal operation in order to remove it. The authors K. Georgios *et al.* (2016) found that biopolymer matrices have an increased susceptibility to hydrolytic degradation during melt processing in the presence of a small amount of moisture, which negatively affects the adhesion mechanism due to the high hygroscopicity of natural fibres. Natural fibre is hydrophilic and polar in nature, so it may have limited compatibility with the polymer matrix. In the work of A. More (2021) methods of improving the interfacial adhesion between the flax fibre and the polymer matrix due to chemical and physical treatment of the fibre surface are defined. The results of similar studies are presented in the paper of S. Kalia (2016). The scientist focused on environmentally friendly methods of improving compatibility between hydrophilic natural fibres and hydrophobic polymer matrices using plasma treatment of natural fillers.

Conclusions

The study revealed that biocomposite materials with a filler content of 200 wt. parts exhibit higher compressive strength (75.8 MPa) compared to those with a lower filler content of 190 wt. parts. The strength of biocomposites increases at a higher content of filler particles (200 wt. parts), which is determined by the ability of coffee grounds particles to deform as a result of compression during formation. Under pressure, the degree of tension in the local volumes of coffee grounds particles decreases due to the mobility of the filler molecules, in contrast to the rigid framework of the glutin matrix macromolecules, which form a structure with an increased stress state during the formation process. The increase in compressive strength in the case of forming biocomposites with a lower density (1.17 g/cm^3) is associated with the optimal degree of compaction of the biocomposite material, the filler particles of which form physical and chemical bonds with the active groups of glutin macromolecules.

Formation of biocomposite materials according to the main mode of thermo-mechanical treatment (1 hour 150°C + pressing + 1 hour 150°C) provides the highest value (79.6 MPa) of compressive strength. The fluidity of the glutinous binder increases at the optimal length of exposure in the thermal field, as a result of which glutinous macromolecules penetrate and are evenly distributed on the surface and in the voids of the coffee grounds particles. This aids in the structuring of the biocomposite material, which involves the formation of additional physical and chemical bonds between the compacted components of the composition under the influence of a thermal field.

The impact toughness of biocomposite materials increases to 3.55 kJ/m^2 in the case of use in the process of forming biocomposites with a specific load of 8 MPa, that is due to the content of coffee beans particles in the glutinous matrix. Coffee beans particles have low mechanical characteristics and are less deformed during pressing under the influence of a specific load of 8 MPa compared to pressing under a pressure of 11 MPa. The increase in resistance to the influence of dynamic loads occurs due to the formation of the optimal density of the biocomposite material, which is determined by the low degree of deformation of the coffee grounds particles. The use of a specific load of 8 MPa during the formation of a biocomposite material allows to improve the structuring of glutinous biocomposites due to the formation of new physicochemical bonds that is confirmed by the presence of asymmetric deformation $-CH_3$ and deformation $-N-H$ vibrations, as well as valence $-C=O-$ and $-C=C-$ oscillations. The formation of biocomposites using a specific load of pressing of 11 MPa leads to the intensification of the structuring process, which is determined by the shift of the absorption bands to the region of lower wave numbers. This indicates the formation of a material with an increased degree of tension and reduced resistance to the influence of dynamic loads.

In the future, it is planned to determine the mechanical properties of biocomposite materials depending on the concentration of glutin in the water solution and the temperature of thermo-mechanical treatment.

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Conflict of Interest

None.

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Розробка клейових біокомпозитних матеріалів, наповнених кавовою гущею

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Анотація. Інтенсивний розвиток біокомпозитних матеріалів пов'язаний з використанням відходів сільськогосподарського виробництва або харчової промисловості як сировини. Така сировина є відновлювальною та екологічно чистою, але потребує спеціальної обробки для підготовки до використання як наповнювач і розробки методів формування біокомпозитних виробів, що визначає високу актуальність досліджень у цьому напрямку. Метою роботи було вивчення інтенсивності впливу механічних і теплових полів на механічні властивості та характер структуризації клейових біокомпозитних матеріалів з високим вмістом кавової гущі (190-200 мас. частин). Технологія формування біокомпозитних матеріалів полягала в термічній обробці композиції. Наступні етапи – пресування та витримка композиції при температурі 150 °C під тиском 8-11 МПа. У роботі використано методи визначення міцності при стисненні та ударної в'язкості. Також застосовано метод інфрачервоної спектроскопії для вивчення процесів структуризації. Було встановлено, що використання кавової гущі в кількості 200 мас. частин забезпечує підвищення міцності при стисненні до 75,8 МПа за умови формування біокомпозитного матеріалу з густиною 1,17 г/см^3. Збільшення стійкості біокомпозитів до динамічних навантажень спостерігається при введенні наповнювача в кількості 190 мас. частин із попереднім пресуванням при специфічному навантаженні 8 МПа. Практичне значення цієї роботи полягає в розробці оптимального режиму термомеханічної обробки, що передбачає максимальне витримування композиції в прес-формі в тепловому полі протягом 2 годин, що підвищує механічні властивості клейових біокомпозитних матеріалів

Ключові слова: клейова матриця; термомеханічна обробка; міцність при стисненні; ударна в'язкість; ІЧ-спектрограма; структуризація